Vol. X, Part 1

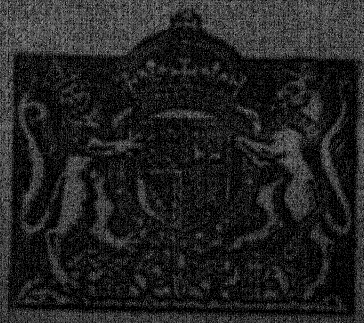
February, 1940

UNIVERSITY LIBRARY
13 MAR 1940
ALLAHABAD

THE INDIAN JOURNAL OF AGRICULTURAL SCIENCE

Issued under the authority of

The Imperial Council of Agricultural Research



Annual subscription
Rs. 15 or 23s. 6d.

Price per part
Rs. 3 or 5s.

Published by the Manager of Publications, Delhi
Printed at the Manager, Government of India Press, New Delhi
1940

List of Agents in India from whom Government of India Publications are available.

(a) Provincial Government Book Depots.

Assam :—Superintendent, Assam Secretariat Press, Shillong.
Bihar :—Superintendent, Government Printing, P. O. Gulzarbagh, Patna.
Bombay :—Superintendent, Government Printing and Stationery, Queen's Road, Bombay.
Central Provinces :—Superintendent, Government Printing, Central Provinces, Nagpur.
Madras :—Superintendent, Government Press, Mount Road, Madras.
North-West Frontier Province :—Manager, Government Printing and Stationery, Peshawar.
Orissa :—Press Officer, Secretariat, Cuttack.
Punjab :—Superintendent, Government Printing, Punjab, Lahore.
Sind :—Manager, Sind Government Book Depot and Record Office, Karachi (Sadar)
United Provinces :—Superintendent, Printing and Stationery, U. P., Allahabad.

(b) Private Booksellers.

Advani & Co., The Mall, Cawnpore.
Aero Stores, Karachi.
Army Musketry Stores, Mega (Punjab).*
Banthiya & Co., Ltd., Station Road, Ajmer.
Bengal Flying Club, Dum Dum Cantt.†
Bhawnani & Sons, New Delhi.
Bombay Book Depot, Charni Road, Girgaon, Bombay.
Book Company, Calcutta.
Booklover's Resort, Talkad, Trivandrum, South India.
British Book Depot, Lucknow.
British Book Depot, Rissalpore.
British Stationery Mart, Booksellers, Peshawar Cantt.
Buckingham & Co., Booksellers and Stationers, Greenwood Street, Station City.
Burma Book Club, Ltd., Rangoon.
Cambridge Book Co., Booksellers, New Dak Bungalow Road, Patna.
Chandrakant Chhunnilall Vora, Ahmedabad.
Chatterjee & Co., 9, Bacharam Chatterjee Lane, Calcutta.
Chitney & Sons, Booksellers, etc., Dhantoli, Nagpur, C.P.
Chukervertty, Chatterjee & Co., Ltd., 15, College Square, Calcutta.
Das Gupta & Co., 54/3, College Street, Calcutta.
Dastane Brothers, Home Service, 456, Raviwar Peth, Poona 2.
Delhi and U. P. Flying Club, Ltd., Delhi.†
Deshmukh Book Depot, Station Road, Sholapur.
English Book Depot, Ferozepore.
English Bookstall, Karachi.
English Book Depot, Taj Road, Agra.
English Book Store, Abbottabad, N.-W. F. P.
Faqir Chand Marwah, Peshawar Cantonment.
Higginbothams, Madras.
Hindu Library, 137/F, Balaram De Street, Calcutta.
H. L. College of Commerce, Co-operative Stores, Ltd., Ahmedabad.
Hyderabad Book Depot, Chaderghat, Hyderabad (Deccan).
Ideal Book Depot, Rajpur Road, Dehra Dun and Bombay Bazar, Meerut.
Imperial Book Depot & Press, Near Jama Masjid (Machliwalan), Delhi.
Imperial Publishing Coy., Lahore.
Indian Army Book Depot, Daryaganj, Delhi.
Indian School Supply Depot, Central Avenue, South, P. O. Dharamtala, Calcutta.
International Book Service, Poona 4.
Jain & Bros., Sarafa Road, Gwalior, Messrs. M. B.
Jaina & Bros., Mori Gate, Delhi and Connaught Place, New Delhi, Messrs. J. M.
Joshi News Agent, Devgad Baria, via Piplod, Bombay, Mr. V. G.
Kamala Book Depot, 15, College Square, Calcutta.
Kapur & Co., 9, Commercial Buildings, The Mall, Lahore, Messrs. N. C.
Karnataka Sahitya Mandir, Publishers and Direct Importers, Dharwar (S. Sind).
Kauls & Co., 9a, Bentinck Road, Karachi (Sadar).
Kitabistan, 17-A, City Road, Allahabad.
Krishnaswami & Co., Tiruvarumbur, P. O., Trichinopoly Dist., Messrs. S.
Lahiri & Co., Ltd., Calcutta, Messrs. S. K.
London Book Co. (India), Arbab Road, Peshawar, Murree, Nowshera, Rawalpindi.
Lyall Book Depot, Lyallpore.
Malhotra & Co., Post Box No. 94, Lahore, Messrs. U. P.
Mathur & Co., Messrs. R. S., Chatur-Vilas, Panta, Civil Lines, Jodhpur (Rajputana).
Minerva Book Shop, Anarkali Street, Lahore.
Modern Book Depot, Bazar Road, Station Cantt.
Mohanlal Dossabhai Shah, Rajkot.
Mohan News Agency, Booksellers, etc., Kotah (Rajputana).
National Welfare Publicity, Ltd., Mangalore.
New Book Co., "Kitab Mahal", 188-90, Hornby Road, Bombay.
Newman & Co., Ltd., Calcutta, Messrs. W.
Oxford Book and Stationery Company, Delhi, Lahore, Simla, Meerut and Calcutta.
Parikh & Co., Baroda, Messrs. B.
Pioneer Book Supply Co., 20, Shib Narayan Das Lane, Calcutta and 219, Cloth Market, Delhi.
Popular Book Depot, Grant Road, Bombay.
Punjab Religious Book Society, Lahore.
Punjab Sanskrit Book Depot, Lahore.
Raghunath Prasad & Sons, Patna City.
Rama Krishna & Sons, Booksellers, Anarkali, Lahore.
Ram Krishna Bros., Opposite Bhimrambux, Poona City.
Ramesh Book Depot & Stationery Mart, Kashmere Gate, Delhi.
Ray & Sons, 43, K. & L. Edwardes Road, Rawalpindi, Murree and Peshawar, Messrs. J.
Reliance Stores, Booksellers, Princess Street, Karachi.
Roy Chowdhury & Co., 72, Harrison Road, Calcutta, Messrs. N. M.
Saraswati Book Depot, 15, Lady Hardinge Road, New Delhi.
Sarcar & Sons, 15, College Square, Calcutta, Messrs M. C.
Sharada Mandir, Ltd., Nai Sarak, Delhi.
Standard Book Depot, Cawnpore.
Standard Book Depot, Lahore, Delhi and Simla.
Standard Bookstall, Karachi.
Standard Bookstall, Quetta.
Standard Law Book Society, 79/1, Harrison Road, Calcutta.
Subjan, Bookseller & Publisher, Bilaspur, C. P., Mr. M. A.
Swaminatha Sivam & Co., Puddukotah, Messrs. P. N.
Tanwerala & Sons, Booksellers, Sangli.
Tara & Sons, Razmak (India), Messrs. R. S.
Taraporevala Sons & Co., Bombay, Messrs. D. B.
Thacker & Co., Ltd., Bombay.
Thacker, Spink & Co. (1933), Ltd., Calcutta.
Tripathi & Co., Booksellers, Prince Street, Kalbadevi Road, Bombay, Messrs. N. M.
Universal Books Depot, Booksellers, News Agents, etc., Kasauli.
University Book Agency, Kacheri Road, Lahore.
Upper India Publishing House, Ltd., Literature Palace, Aminuddaula ,, Lucknow.
Varadachary & Co., Madras, Messrs. P.
Venkatasubbiah, A., Law Bookseller, Vellore.
Whyte & Co., Allahabad, Calcutta and Bombay, Messrs. A. H.
Young Man & Co. (Regd.), Egerton Road, Delhi.

* Agent for Army publications only.
† Agents for publications on Aviation only.

CONTENTS

VOL. X, PART I

(February, 1940)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal

Original articles—

		PAGE
POISONOUS PLANTS OF INDIA . . .	*R. N. Chopra, C.I.E., M.D., Sc.D. (Cantab.), F.R.C.P. (Lond.), Bt.-Col., I.M.S. (Retd.) and R. L. Badhwar, M.Sc.*	1
SAMPLING OF SUGARCANE FOR CHEMICAL ANALYSIS (WITH ONE TEXT-FIGURE)	*B. P. Vagholkar, L. Ag.; N. B. Patwardhan, B.Ag. and S. Subramonia Iyer, M.A.*	45
STUDIES IN INDIAN RED SOILS, I. BUFFER CURVES AND BASE-EXCHANGE REACTIONS (WITH NINE TEXT-FIGURES)	*S. P. Raychaudhuri and A. B. Nandy Mazumdar*	62
FORMATION OF OIL IN SOME OLEIFEROUS *BRASSICAE*	*Ali Mohammad, M.Sc. (Agri.), L.Ag. and Sultan Ahmad, B.Sc. (Agri.)*	82
A NEW *CORTICIUM* ON ORANGE STEM (WITH PLATE I)	*J. F. Dastur, M.Sc.*	89

Research Notes—

DELAYED GERMINATION IN SESAME (*SESAMUM INDICUM*) (WITH ONE TEXT-FIGURE)	*R. H. Richharia and D. R. Dhodapkar*	93
A SPECIES OF *PHYLLACTINIA* OCCURRING ON ALMOND (*PRUNUS AMYGDALUS*) (WITH PLATE II)	*M. Asghar Ginai, M.Sc. (Hons.)*	96

Notes 98

Review—

PLANT HORMONES AND THEIR PRACTICAL IMPORTANCE IN HORTICULTURE 100



CONTENTS

VOL. X, PART II

(April, 1940)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal.

Original articles—

		PAGE.
FINAL REPORT ON THE SCHEME OF INVESTIGATION ON THE WHITE-FLY OF COTTON IN THE PUNJAB	*M. Afzal Husain, M.A. (Cantab.), I. A. S. and K. N. Trehan*	101
A NEW PEST (*ACANTHIOPHILUS HELIANTHI* ROSSI, TRYPETIDAE) OF SAFFLOWER IN INDIA (WITH PLATE III)	*Hem Singh Pruthi, M.Sc., Ph. D. (Cantab.), F. N. I. and H. L. Bhatia, M.Sc.*	110
MICRO-BIOLOGICAL DECOMPOSITION OF PLANT MATERIALS, I. CHANGES IN THE CONSTITUENTS OF RICE STRAW (KANAK-TARA) PRODUCED BY MICRO-ORGANISMS PRESENT IN SOIL SUSPENSION UNDER AEROBIC, ANAEROBIC AND WATERLOGGED CONDITIONS (WITH ONE TEXT-FIGURE)	*S. S. Guha Sircar ; S. C. De and H. D. Bhowmick*	119
II. A NOTE ON THE CHANGES IN THE METHOXYL AND NITROGEN CONTENT OF LIGNIN OF RICE STRAW DURING ITS DECOMPOSITION BY MICRO-ORGANISMS	*S. S. Guha Sircar ; S. C. De and H. D. Bhowmick.*	152
STUDIES ON THE CHEMICAL CONSTITUENTS OF INDIAN LATERITIC AND RED SOILS, I. DETERMINATION OF FREE SESQUIOXIDE COMPONENTS	*S. P. Raychaudhuri and M. Sulaiman*	158
THE DEPTH OF THE SURFACE LAYER OF THE SOIL TAKING PART IN THE DIURNAL EXCHANGE OF MOISTURE WITH THE AIR LAYERS NEAR THE GROUND	*A. K. Mallik, M.Sc., B.Sc. (Ag.), Assoc. I.A.R.I.*	164
CONVERSION OF CANE MOLASSES INTO MANURE BY THE BIOLOGICAL METHOD AND THE RESULTS OF THE CROPPING TESTS WITH THE MANURES PREPARED (1938-39)	*H. D. Sen, M. Sc., Ph. D. (Lond.), D. I. C.*	172

		PAGE
A REVIEW OF THE APPLICATION OF STATISTICAL THEORY TO AGRICULTURAL FIELD EXPERIMENTS IN INDIA	*P. C. Mahalanobis* . .	192
A NOTE ON THE ANALYSIS OF 3^3 AND 3^4 DESIGNS (WITH THREE FACTOR INTERACTIONS CONFOUNDED) IN FIELD EXPERIMENTS IN AGRICULTURE	*M. Vaidyanathan, M.A., L. T., F.S.S. and S. Subramonia Iyer, M.A., F.S.S.*	213
Notes—		237
Review—		
BIOLOGICAL ABSTRACTS		240

CONTENTS

VOL. X, PART III

(June, 1940)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal.

Original articles—

		PAGE
THE GENUS *FUSARIUM*, III. A CRITICAL STUDY OF THE FUNGUS CAUSING WILT OF GRAM (*CICER ARIETINUM* L.) AND OF THE RELATED SPECIES IN THE SUB-SECTION ORTHOCERA, WITH SPECIAL RELATION TO THE VARIABILITY OF KEY CHARACTERISTICS	*G. Watts Padwick,*	241
CYTOLOGICAL STUDIES IN *GOSSYPIUM*. I. CHROMOSOME BEHAVIOUR IN THE INTERSPECIFIC HYBRID *G. ARBOREUM* × *G. STOCKSII* (WITH 13 TEXT-FIGURES)	*P. Abraham, B.A., M.Sc.*	285
MORPHOLOGY OF THE SOMATIC CHROMOSOMES OF THREE ASIATIC COTTONS (WITH THREE TEXT-FIGURES)	*P. Abraham, B.A., M.Sc.*	299
ON THE NATURE OF REACTIONS RESPONSIBLE FOR SOIL ACIDITY, VI. THE VARIABILITY OF THE TOTAL NEUTRALIZABLE ACID OF COLLOID SOLUTIONS OF HYDROGEN CLAYS (WITH SEVEN TEXT-FIGURES)	*R. P. Mitra, D.Sc., S. K. Mukherjee, M.Sc. and S. N. Bagchi, M.Sc.*	303
VII. THE ELECTROCHEMICAL PROPERTIES OF COLLOIDAL SOLUTIONS OF HYDROGEN CLAYS (WITH 10 TEXT-FIGURES)	*R. P. Mitra, D.Sc.*	317
THE BASE BINDING CAPACITIES OF HYDROGEN CLAYS AS DETERMINED BY DIFFERENT METHODS	*R. P. Mitra, D.Sc. and A. K. Mitra, M.Sc.*	344
STUDIES ON SOIL TEMPERATURES IN RELATION TO OTHER FACTORS CONTROLLING THE DISPOSAL OF SOLAR RADIATION (WITH FIVE TEXT-FIGURES)	*R. K. Dravid, M.Sc.*	352

		Page
A Study of Plot Size and Shape Technique for Field Experiments on Sugarcane	*B. P. Vagholkar, L.Ag.; V. N. Apte, B.Ag. (Bom.) and S. Subramonia Iyer, M.A., F.S.S.*	388
Interspecific Hybridization between Asiatic and New World Cottons (with Plates IV and V)	*K. C. Amin, B.Ag.*	404
Genetical Studies in *Coffea arabica* L.—A Preliminary Study with Young Leaf Colour and Ripe Pericarp Colour	*R. L. Narasimha Swamy, M.Sc.*	414
Insect Pollinators of *Toria* (*Brassica napus* Linn. var. *dichotoma* Prain) and *Sarson* (*B. campestris* Linn. var. *sarson* Prain) at Lyallpur	*Khan A. Rahman, B.Sc. (Edin.), Ph.D. (Cantab.), F.R.E.S.*	422
The Hot Fermentation Process for Composting Town Refuse and other Waste Materials,		
III. The Hot Fermentation vs. Aerobic System of Composting (with Plate VI)	*C. N. Acharya, M.Sc., Ph.D., F.I.C.*	448
IV. The Hot Fermentation vs. Poudrette Methods for Disposal of Night Soil	*C. N. Acharya, M.Sc., Ph.D., F.I.C.*	473
Notes		489
Review—		
Supplement to Root Nodule Bacteria and Leguminous Plants	..	492

CONTENTS

VOL. X, PART IV

(August 1940)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal.

Original articles—

		PAGE
THE EFFECT OF DIFFERENTIAL IRRIGATION AND SPACING ON THE FIELD BEHAVIOUR AND QUALITY OF CAMBODIA Co 2 COTTON (WITH TWO TEXT-FIGURES)	*V. Ramanatha Ayyar, L. Ag.; Nazir Ahmad, M.Sc. Ph.D., F. Inst. P. and N. C. Thirumalachari, B.Sc. Ag.*	493
INDIGENOUS AND EXOTIC COTTONS OF IRAN (WITH TWO TEXT-FIGURES)	*M. A. A. Ansari*	522
MEGASPROGENESIS AND THE ORIGIN OF TRIPLOIDS IN *SACCHARUM* (WITH PLATES VII-XVI)	*S. Narayanaswami, M.Sc.*	534
THE DISTINGUISHING CHARACTERS AND BEHAVIOUR OF SOME GRAPE VINE VARIETIES INTRODUCED AT LYALLPUR IN THE PUNJAB (WITH THREE TEXT-FIGURES)	*Lal Singh, B.Sc. (Hons.), M.Sc. (Calif.) and Sham Singh, B.Sc. (Agri.) (Pb.), Ph. D. (Bristol)*	552
A STUDY OF THE PRE-ORCHARD LIFE OF CERTAIN ROOTSTOCKS FOR *CHINEE* ORANGE (*CITRUS SINENSIS* OSBECK) AND ACID LIME (*C. AURANTIFOLIA* (CHRISTM) SWINGLE) AT KODUR (WITH PLATES XVII-XXI AND ONE TEXT-FIGURE)	*K. C. Naik, B. Ag. (Bom.), M.Sc. (Bristol)*	601
A REMARKABLE WILD HOST PLANT OF THE COTTON-STEM WEEVIL, *PEMPHERES AFFINIS* FST., FROM SOUTH INDIA, AND ITS PARASITIC ASSOCIATES (WITH (PLATES XXII-XXVII)	*P. N. Krishna Ayyar*	640
STUDIES ON THE ROOT-ROT DISEASE OF COTTON IN THE PUNJAB, VIII. FURTHER STUDIES ON THE PHYSIOLOGY OF THE CAUSAL FUNGI	*Jai Chand Luthra, M.Sc., D.I.C. (Lond.), I.A.S.; R. Sahai Vasudeva, B.Sc., Ph. D. (Lond.), D.I.C. (Lond.) and Mohammad Ashraf, B.Sc. (Agri.)*	653

		Page
Statistical Notes for Agricultural workers, No. 25. A Simplified Method of Analysis of Quasi-Factorial Experiments in Square Lattice with a Preliminary Note on Joint Analysis of Yield of Paddy and Straw (with one text-figure)	*R. K. Nair and P. C. Mahalanobis*	663
The Analysis of Simple Non-Symmetrical Experiments	*P. V. Krishna Iyer*	686
A Supplementary Note on the Analysis of 3^3 and 3^4 Designs (with Three-Factor Interactions Confounded) in Field Experiments in Agriculture	*S. Subramonia Iyer, M.A., F. S. S.*	691
Note		693
Review—		
Vegetative Propagation of Tropical and Sub-tropical Plantation Crops		695

CONTENTS

VOL. X, PART V

(October 1940)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal.

Original articles—

		PAGE
THE PROBLEM OF INTER-PROVINCIAL PLANT QUARANTINES IN INDIA	*G. Watts Padwick and B. N. Uppal*	697
THE GENUS *FUSARIUM*, IV. INFECTION AND CROSS-INFECTION TESTS WITH ISOLATES FROM COTTON (*GOSSYPIUM* SP.), PIGEONPEA (*CAJANUS CAJAN*) AND SUNN-HEMP (*CROTALARIA JUNCEA*) (WITH PLATES XXVIII AND XXIX)	*G. Watts Padwick; M. Mitra and P. R. Mehta*	707
SUGARCANE VARIETAL TRIALS IN THE DECCAN CANAL-TRACT AT PADEGAON, 1933-38 (WITH PLATES XXX-XXXII AND TWO TEXT-FIGURES)	*B. P. Vagholkar, L.Ag. and N. B. Patwardhan, B.Ag.*	716
EMBRYO OF THE INDIAN MANGOES (*MANGIFERA INDICA* LINN.) (WITH PLATES XXXIII AND XXXIV AND THREE TEXT-FIGURES)	*P. K. Sen and P. C. Mallik*	750
THE EFFECT OF AMMONIACAL AND NITRATE NITROGEN ON THE YIELDS OF THE RICE PLANT	*R. H. Dastur* . .	761
CARBON TRANSFORMATIONS DURING THE DECOMPOSITION OF CANE MOLASSES UNDER SWAMP SOIL CONDITIONS (WITH ONE TEXT-FIGURE)	*G. Narasimhamurthy* .	768
ON THE INDEX OF NITROGEN LEVEL IN SOILS	*P. E. Lander, D.Sc., F.I.C., I.A.S. and M. R. Madhok, Ph.D, Assoc. I.A.R.I.*	773
EUPELMELLA PEDATORIA FERR., A PARASITE OF THE COTTON-STEM WEEVIL (*PEMPHERES AFFINIS* FST.) FROM SOUTH INDIA (WITH PLATE XXXV AND THREE TEXT-FIGURES)	*P. N. Krishna Ayyar* .	776

		PAGE
THE ANATOMY, LIFE AND SEASONAL HISTORIES OF STRIPED MOTH BORERS OF SUGARCANE IN NORTH BIHAR AND WEST UNITED PROVINCES (WITH PLATES XXXVI AND XXXVII AND FIVE TEXT-FIGURES)	*B. D. Gupta, M.Sc., Assoc. I.A.R.I.*	787
CHILO TRYPETES BISSET (PYRALIDAE), A NEW PEST OF SUGARCANE FROM THE PUNJAB (WITH PLATE XXXVIII)	*Khan A. Rahman, B.Sc. (Edin.), Ph.D. (Cantab.), F.R.E.S. and D. N. Tandon, L.Ag., B.Sc. (Agri.)*	818
STUDIES ON EDIBLES FROM *BORASSUS FLABELLIFER* (PALMYRA-PALM) WITH SPECIAL REFERENCE TO *NIRA* OR SWEET TODDY	*K. Mitra, M.B., D.P.H. (Cal.), D.T.M.&H. (Eng.), F.S.S. (Lond.) and H. C. Mittra, M.Sc.*	824
A RAPID METHOD OF MEASUREMENT OF LEAF AREAS OF PLANTS (WITH THREE TEXT-FIGURES)	*N. C. Thirumalachary, B.Sc. (Ag.)*	835
LINKAGE RELATIONS OF THE WHITE-POLLEN FACTOR IN ASIATIC COTTONS	*G. K. Govande* . .	842
A NOTE ON THE SHAPE OF BLOCKS IN FIELD EXPERIMENTS (WITH FOUR TEXT-FIGURES)	*Ramji Narain, D.Sc., Ph.D. and Azmat Singh*	844
A NOTE ON THE DESIGN AND ANALYSIS OF COMPACT EXPERIMENTS WITH THREE OR FOUR RESTRICTIONS	*P. V. Krishna Iyer, M.A.*	854
Notes		860
Review—		
THE BREEDING OF HERBAGE PLANTS IN SCANDINAVIA AND FINLAND		862

CONTENTS

VOL. X. PART VI

(December 1940)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal.

Original articles—

		PAGE.
THE GENUS *FUSARIUM*, V. *FUSARIUM UDUM* BUTLER, *F. VASINFECTUM* ATK. AND *F. LATERITIUM* NEES VAR. *UNCINATUM* WR. (WITH PLATES XXXIX-XLI)	*G. Watts Padwick* . .	863
INVESTIGATIONS ON *SPATHIUS CRITOLAUS* NIXON, AN IMPORTANT BRACONID PARASITE OF THE COTTON-STEM WEEVIL, *PEMPHERES AFFINIS* FST. OF SOUTH INDIA (WITH PLATES XLII AND XLIII AND TWO TEXT-FIGURES)	*P. N. Krishna Ayyar* .	879
THE ROLE OF FOOD AND ITS CONSTITUENTS ON THE PRODUCTIVITY AND LONGEVITY OF THE COTTON-STEM WEEVIL, *PEMPHERES AFFINIS* FST. (WITH ONE TEXT-FIGURE)	*P. N. Krishna Ayyar and V. Margabandhu*	901
STUDIES ON THE COTTON JASSID (*EMPOASCA DEVASTANS* DISTANT) IN THE PUNJAB, I. VARIETAL SUSCEPTIBILITY AND DEVELOPMENT OF THE PEST ON DIFFERENT VARIETIES OF COTTON	*Piare Mohan Verma and Mohammad Afzal*	911
STUDIES ON *SCHISTOCERCA GREGARIA* FORSK., X. ROLE OF WATER IN THE BIONOMICS OF THE DESERT LOCUST	*M. Afzal Husain, M.A. (Cantab.), I.A.S.; Taskhir Ahmad, Ph. D. (Cantab.), and C. B. Mathur, M. Sc. (Luck.)*	927
BIONOMICS AND CONTROL OF THE FIG TREE BORER (*BATOCERA RUFOMACULATA* DE GEER, COLEOPTERA: LAMIIDAE) (WITH PLATE XLIV)	*M. Afzal Husain, M.A., I.A.S. and Abdul Wahid Khan, M.Sc. (Agri.)*	945
THE INFLUENCE OF THE RAINFALL DISTRIBUTION ON THE COTTON YIELDS AT THE GOVERNMENT EXPERIMENTAL FARMS AT AKOLA AND JALGAON (WITH THREE TEXT-FIGURES)	*R. J. Kalamkar, B.Sc., B. Ag., Ph.D. and V. Satakopan, M.A.*	960

		PAGE.
THE INHERITANCE OF MEAN FIBRE-LENGTH, FIBRE-WEIGHT PER UNIT LENGTH AND FIBRE MATURITY OF COTTON (WITH ONE TEXT-FIGURE)	*R. S. Koshal, M.Sc.; A. N. Gulati, M. Sc.and Nazir Ahmad, O.B.E., Ph.D., F. Inst. P.*	975
STUDIES ON KUMAUN HILL SOILS, I. SOIL SURVEY AT THE GOVERNMENT ORCHARD, CHAUBATTIA: FORMATION OF GENETIC GROUPS (WITH PLATE XLV)	*B. K. Mukerji, Ph. D., D.Sc. and N. K. Das, M.Sc., Assoc. I. A. R. I.*	990
THE RELATION OF THE SIZE OF FRUIT TO THE LOSS IN WEIGHT IN STORAGE	*D. V. Karmarkar, M.Sc., Ph.D., A.I.I.Sc., and B. M. Joshi, M.Sc.*	1021
VARIETIES OF CARDAMOM IN CULTIVATION IN MYSORE (WITH PLATE XLVI)	*R. L. Narasimha Swamy, M.Sc.*	1030
Research note—		
CHROMOSOME NUMBER IN BAMBOO (*DENDROCALAMUS STRICTUS*) (WITH ONE TEXT-FIGURE)	*R. H. Richharia and J. P. Kotwal*	1033
Reviews—		
FORESTRY ABSTRACTS		1034
SUPPLEMENT TO THE REVIEW OF APPLIED MYCOLOGY . . .		1035

ORIGINAL ARTICLES

POISONOUS PLANTS OF INDIA

BY

R. N. CHOPRA, C.I.E., M.D., Sc.D. (Cantab.), F.R.C.P. (Lond.),
Brevet-Colonel, I.M.S. (Retd.)

AND

R. L. BADHWAR, M.Sc.

(*Medicinal Plants and Food Poisons Inquiry, Imperial Council of Agricultural Research, School of Tropical Medicine, Calcutta*)

(Received for publication on 3 March 1939)

Introduction

IT is admitted on all sides that the country in which we live is a veritable emporium of drugs containing powerful active principles. Nearly three-fourths of the drugs mentioned in the British and other pharmacopœias grow in a state of nature here and the others can be easily grown. The country has vast resources so far as medicinal plants are concerned, and it abounds in many kinds of perfumes and spices which are known all over the world. India possesses climatic conditions varying from the torrid to the frigid zone. It embraces vast tracts of tropical plains, temperate hills and valleys, irrigated soil, and moist and dry climates. It has in fact been described as an epitome of the climates, seasons and soils of the British Empire. No wonder then that the plants containing active and medicinal principles grow abundantly within its bounds. More than 2,000 such plants have been enumerated in the literature of the indigenous systems of medicine which are alleged to have medicinal properties of some description or other and have been used in indigenous medicine in some form or other. The majority of these plants have not yet been fully investigated.

Many among them are said to contain powerful and toxic principles. If introduced into the body of an animal in relatively small quantities, they will act deleteriously and may cause serious impairment of bodily functions or even death. They injure the basic life principle, the protoplasm of the cells of which the animal body is built up, by virtue of their chemical constituents whose nature may be known or unknown. Such a definition of poisonous plants would exclude plants which act entirely in a mechanical way, such as certain grasses notably *Stipa*, *Aristida* and *Heteropogon*, whose 'seeds' may pierce the skin and produce abscesses or make their way into the salivary ducts of animals and do serious injury; nor would it be desirable to include spiniferous plants which do considerable harm to man and animals. On the other hand, it will include some foodstuffs or fodder plants which may

become deleterious under certain conditions. The harmful effects produced by chemical substances contained may be immediate or cumulative, i.e. they may appear after a period of time when the poison has had time to accumulate in the body in sufficient concentration to produce its deleterious effect after repeated administration. All such plants come under the category of poisonous plants.

Chemical constituents of plants responsible for toxic effects

(1) The first class of these substances are vegetable bases which include amines and alkaloids. As a class these bodies are characterized by their profound physiological action and in many cases their intensely poisonous nature. Some of the amines give a foetid odour to some weeds, and to some mushrooms their poisonous characters. The alkaloids as a rule give a bitter taste to a plant in which they naturally occur, and that in itself is frequently a sufficient protection against livestock eating it, except in unusual cases of hunger. A considerable number of medicinal drugs owe their curative properties to these principles. The grasses as a rule do not contain these bases but they do occur in many of the other families. Examples of alkaloids are strychnine from nux-vomica, aconitine from aconites, atropine and allied alkaloids from belladonna, nicotine from tobacco, morphine from poppy, etc.

(2) Another class of poisonous substances are represented by glucosides which form a large group and are much wider in occurrence than alkaloids. Many are non-toxic but quite a large number of them are intensely poisonous. They have generally a bitter taste and occur in many of the plant extracts used in medicine. Well-known examples of toxic glucosides are those occurring in the Oleander family (*Apocynaceæ*) and *Digitalis* (*Scrophulariaceæ*).

A group of glucosides which are important from the point of view of livestock-poisoning is represented by the cyanogenetic glucosides which contain hydrocyanic acid bound up in them; this is liberated by enzymes mostly occurring in the same plants. As the name implies they split in the animal body, liberating sufficient quantities of hydrocyanic acid to produce fatal results. The well-known representative of this class is one occurring in bitter almonds and known as amygdalin. They also occur in a number of grasses and members of the pea and rose families, etc.

Another group of glucosides, when agitated with water, produce soapy foam and to these the name of saponins is given. In the vegetable kingdom they occur in at least 400 plants belonging to 50 different families. They are particularly poisonous to certain lower animals, for example fishes, frogs, insects, etc. The fish are killed by these bodies in such high dilutions as 1 in 200,000 or more. In higher animals, when taken by mouth, they produce gastro-intestinal irritation, vomiting and diarrhœa. In cold-blooded animals, such as fishes, they produce paralysis of the respiratory organs. They produce hæmolysis when they come in contact with blood and have an acrid taste. Common examples containing saponins are soap-nut, soap-bark and soap-root.

(3) The third group of poisons is furnished by essential or volatile oils which give characteristic odours to plants. These bodies are characterized

by their insecticidal and insect-repellent properties, while in man and livestock they produce toxic effects by gastro-intestinal irritation. Common examples are those occurring in eucalyptus, in absinth which produces convulsions by its action on the nervous system, the pine family and that produced from mustard seed by the action of an enzyme, etc. Cattle do not as a rule feed on the plants containing the toxic essential oils.

(4) The fourth group of toxic substances are known as toxalbumins which occur in castor, croton and abrus seeds. These are essentially blood poisons and are responsible for frequent losses among livestock. Animals can, however, become immune to these bodies if they are given in small and gradually increasing doses, but the immunity is of a specific nature, i.e. against that particular toxalbumin and not against others.

(5) Lastly there are groups of substances called resins such as those occurring in podophyllum, bitters such as are found in wild members of the cucumber family, for example colocynth, phenolic compounds such as those found in many members of the cashew family. Other highly toxic principles are andromedotoxin occurring in many members of the rhododendron family, toxic oils such as croton oil, picrotoxin, a convulsant poison found in *Anamirta cocculus* (Linn.) W. and A. (poison berry) which is a climbing shrub of the Indian forests, and neutral principles, organic acids and their salts, etc. All these have been responsible for poisoning in man and animals.

Factors affecting toxicity

The amount of poisonous substances present in plants is dependent upon several factors, for example the nature of the soil, the climate, the season, the stage of growth of a plant, the nature and intensity of light, cultivation, etc. Fresh, green plants may be poisonous and in a dried condition the toxicity may be lost, for example in buttercups and other plants which have volatile active principles. Toxicity may be lost by cultivation as in the case of gourds, while the toxic principles in cinchona and oleander do not deteriorate through cultivation. The stage of growth of a plant is perhaps the most important factor in determining its toxicity.

Susceptibility of animals to plants varies enormously. Rabbits are insensitive to the atropine group and birds stand large doses of strychnine. Young mammals are generally more susceptible than old. The condition of the animal, personal idiosyncracy, tolerance and immunity also play a part in determining the degree of susceptibility to the poison.

To endeavour to compass within this paper even a comprehensive bird's eye view of poisonous plants of India would be impossible. Our object is to put before the reader as briefly as possible the importance of this work from its economic and toxicological aspects in relation to man and lower animals.

Toxicological aspects

I. Cryptogams (the flowerless plants)

The toxicological aspects of the cryptogams are very little known so far as India is concerned and we will make only brief reference to them.

(*a*) *Bacteria*

The bacteria are among the simplest form of plant life and are met with universally. The majority of them are harmless but some are injurious to man and animals. They produce deleterious effects in two ways: Firstly as parasites, when they derive their nourishment from living animals and many of them produce, within the body, toxins which are harmful. Secondly many saprophytic bacteria produce poisonous substances, especially such as those occurring in putrid flesh, fish and other decaying organic matter. It is not our intention to include them in this paper as, although they belong to the vegetable kingdom, they are a class by themselves and do not come under the category of poisonous plants.

(*b*) *Algæ*

The algæ that cause poisoning are mostly those which are found in stagnant waters. The normally offensive odour may be sufficient to indicate their presence, but only a microscopic examination can determine just what the forms of algæ present may be. Blue-green algæ, as a group, are perhaps the most pronounced in their toxic effect. Prof. Parker and other workers have shown that when odours in water are pronounced, the microscopic, organisms are present in considerable numbers. According to him, of the organisms which produce objectionable and deleterious qualities in waters, the microscopic ones are the more important and very few cases have been observed in which really serious trouble in water supplies could be attributed directly to the growth of larger plants. In any study of the algæ from this point of view, however, account must be taken of the products of decomposition by the associated bacteria since poisoning may be produced by the toxins produced by bacteria rather than by the algæ.

Certain algæ, such as *Microcystis flos-aquæ* (Wittr.) Kirch., *Aphanizomenon flos-aquæ* (Linn.) Ralfs. and species of *Anabæna*, etc. form on the surface of water what is generally called water bloom. The presence of water bloom on the surface of lakes, ponds, and other open sheets of water is distasteful to bathers and obnoxious to those living in the vicinity. Livestock compelled to drink water containing water bloom are reported to have been poisoned. In Minnesota, (U. S. A.) during recent years, horses, cattle, sheep, and turkeys have died in large numbers on the shores of lakes where water bloom is present. All the above-mentioned algæ forming water bloom have been recorded in various parts of India but no work has been done in connexion with their toxic effects. According to Dr Bhardawaja of the Benares Hindu University, water blooms containing these species occur commonly on the surface of many temple tanks in different parts of India. Of the other possibly harmful algæ may be mentioned species of *Nodularia*, *Clathrocystis*, *Nostoc*, *Oscillatoria*, *Pandorina*, and *Volvox* when present in large numbers.

The question of growth of algæ in water reservoirs leads us to a very important public health problem. Although in India very little information is available about the contamination of the water supplies with the group of toxic algæ, we cannot pass over this important question without drawing attention to the importance of checking their growth in the reservoirs of water

supplies. One of the essentials of the algal growth is light. Their growth may, therefore, be prevented, or at any rate considerably reduced, by covering up the reservoirs and cutting off sunlight. Unfortunately, most of the reservoirs for the supply of water to both animals and man in India are generally not covered and are often largely contaminated with algal growth. The removal of organic matter by keeping the source of water supply in as pure a state as possible will no doubt keep down the algal growth but it must be understood that nearly all water contains sufficient organic matter for the growth of algæ, especially the water coming from water-sheds. Growth of algæ can also be successfully prevented by the addition of copper sulphate in dilutions of one in five millions or even higher. This does not render the water deleterious to man and animals.

The problem of toxic algæ is important and deserves the attention of workers in this field.

(c) *Fungi*

i. Some fungi live on the skin and mucous membranes of man and animals and cause various diseases, e.g. ringworm, thrush, etc.

ii. There are others which attack foodstuffs and among these may be mentioned: (1) *Smuts*. Many of these are destructive parasites which invade plants of vital economic importance, such as oats, wheat, millet and other cereals. Some are supposed to be poisonous if taken in large quantities, and others are said to produce irritation of the mucous memberane. There is difference of opinion with regard to the injurious effects produced by particular kinds of smut and hardly any authentic information is available regarding those occurring in India. The subject deserves careful investigation by mycologists. (2) *Rusts*. Annual recurrence of the outbreaks of rust attacks of cereals in India, especially those attacking wheat, is of great economic importance to the country. These, especially the uredo stage, produce inflammation of the mucous membrane of the mouth and nose. The dust coming from the infested straw when the grain is thrashed is stated to cause serious disturbances of the respiratory tract. Very little information is available about the Indian strains. (3) *Ergot*, which grows on rye, is a well known example of a fungus which produces highly poisonous substances, but there is no evidence of its occurrence in India. (4) The poisonous nature of the seeds of darnel (*Lolium temulentum* Linn.), a grass and annual weed of cultivation, especially up-country, is believed to be due to a fungus, and cases of poisoning due to admixture of the seeds with wheat grains are not infrequently reported in India and abroad. Cases of death among livestock have also been reported. The animals should not be allowed to feed on the plants when seeds are formed.

(5) Very variable data are available as regards the poisonous effects of mouldy foodstuffs in India but there appears to be little doubt that the presence of certain species may occasionally produce harmful effects in man and animals. Species of *Mucor*, *Aspergillus*, *Penicillium* and *Fusarium*, etc. deserve special investigation in this connexion. It appears, however, that there is an appreciable difference in the susceptibility of different species of animals to the effects of mouldy foodstuffs. In general it has been stated

that horses, dogs and pigs are more susceptible than ruminants and poultry, while in other animals the case may be the reverse. Very little information is available about the toxicity of moulds occurring in India and the problem requires a thorough investigation because of its great economic importance. In the meantime it would be safer to consider all fungus-infected foodstuffs as deleterious. Acute poisoning with the moulds is rarely met with and if they are taken in small quantities there is hardly any danger. The practice of throwing away mouldy pickles and other edible substances is no doubt a step in the right direction.

iii. The third group of the poisonous fungi belong to the mushroom class. A number of these are edible and many occurring in India are indiscriminately eaten. Cases of fungus poisoning, therefore, are not infrequently met with, particularly in the hills. Unfortunately very little information is available about the poisonous fungi growing in this country and in spite of cases of poisoning, little attention has been paid to the subject.

Stropharia semiglobata (Batsch) Quel. from Khasia hills, *Hypholoma fasiculare* (Huds.) Fr. from Darjeeling and Simla and *Lactarius vellereus* Fr. from Sikkim are regarded as poisonous. There is also evidence on record that there exists in Bengal a fungus which closely resembles an edible form but which contains amanitine or muscarine, the poisonous principle of the foreign *Amanita muscaria* Pers. Recently two mushrooms were sent to us from Kumaon as being poisonous. These were identified as *Collybia* and *Cantharellus*. There are probably many more poisonous species than have really been incriminated as poisons, but on the whole their number may be small and indeed if properly cooked only a few are dangerous. If washed in water and macerated in vinegar before cooking, and if eaten with plenty of bread there is almost no danger in most cases. The safest method, however, is to learn to recognize the edible species and never to eat a fungus until its identity is certain.

Some of the foreign poisonous fungi, e.g. *Lepiota cristata* Quel., *Volvaria gloicephala* Gill., *Amanita muscaria* Pers. and *Amanita phalloides* Secr. are well known. The last-mentioned is responsible for perhaps 90 per cent of the deaths caused by fungus poisoning in Europe, Great Britain, and U. S. A. During the world war, when food scarcity became acute in Germany and Austria, poisoning from fungi appreciably increased. According to Ford there are four main types of mushroom intoxication: (1) Gastro-intestinal in which the attack ceases when the stomach is emptied. (2) General catharsis which is painless. (3) Violent vomiting and pain but no involvement outside the gastro-intestinal tract. (4) Choleriform type producing widespread degeneration of cells.

(*d*) *Lichens*

Very little is known about these symbiotic organisms which consist of algal cells enveloped by the mycelium of the fungus forming a felted mass. Although this group is not to be regarded as a serious menace to livestock, cases of poisoning due to *Parmelia* and *Cretraria* species, etc. are mentioned in foreign literature. *Parmelia molliuscula* has been said to affect sheep and cattle, producing lack of coordination of the hind limbs. In more severe cases

the animal lies down and is unable to move either its front or hind limbs. Little or no information is available about lichens in India and even their systematic botany has not been sufficiently worked out.

(*e*) *Bryophyta* (*liverworts and mosses*)

This is the least-known group of plants from the view-point of poisoning and we have, therefore, nothing to say about it.

(*f*) *Pteridophyta* (*vascular cryptogams*)

This group includes ferns and allied plants, and unfortunately little or no work has been done in India with regard to their toxicity. Greshoff and others have reported the presence of hydrocyanic acid in a number of ferns, especially when young. References to the supposed poisonous properties of the bracken (*Pteris aquilina*) have appeared in the literature for a long time, and Stockman in Great Britain showed that it is poisonous to cattle when eaten in considerable quantities. The plant is found in India. *Aspidium filix-mas*, the male fern, is suspected of being poisonous. The roots are used in medicine and large quantities of it produce hæmorrhagic gastro-enteritis, tremors, weakness, stupor, coma, acute nephritis, and cystitis. Six drachms of the oleoresin have proved fatal in man and three ounces in the cow. This fern is not found in India, but since there are several other foreign species of *Aspidium* which are also suspected of being poisonous it may be worth while to examine Indian representatives of these plants. Some foreign species of *Osmunda*, *Davallia* and *Adiantum* are also suspected of being poisonous, but nothing is known of Indian representatives of these ferns.

Some of the foreign species of *Equisetum* (horsetail) have long been recognized in foreign countries as injurious to cattle and horses. They produce an intoxication in which the animals stagger about and wander aimlessly. There is no information available in India with regard to the Indian horsetail, *Equisetum arvense*, but several European and American workers are convinced that it is definitely poisonous to horses, while others hold a contrary opinion. This plant grows commonly in certain places in India where it might be a menace to livestock.

II. Phanerogams (the flowering plants)

After having given a very brief survey regarding the toxicological aspects of the Cryptogamic flora we will now take up the Phanerogams. Economically this is the most important group both for man and animals from the point of view of everyday necessities of life, *e.g.*, food, medicines, etc. It is probably on account of this that more information is available with regard to this group.

From a toxicological point of view the Phanerogams may be divided into two main groups.

i. Plants poisonous to man and livestock

(*a*) *Poisonous to man.*—Primitive man in his quest for food must have come across plants containing poisonous principles by accident and by experience must soon have learned to avoid them. He even made use of them

for the purpose of fighting against his enemies and for procuring his food by killing animals with them. Many of the forest tribesmen of India, numbering 18 millions, use these poisonous plants to fight their enemies and to kill game. Among the civilized, poisoning by accident, ignorance or intention is met with even at the present time. On the whole, our knowledge is fairly well advanced so far as the relationship of poisonous plants to mankind is concerned.

Some poisonous plants have been used for criminal purposes, but the majority of them are used as medicinal agents for the amelioration of human suffering. It is well known that many plants, that are harmful to life in large quantities, produce remarkably beneficial effects in small regulated doses. There is no doubt that in a country like India with a luxuriant flora, cases of poisoning with unknown plants do occur, but these are not common. From the economic point of view, the abundance of this group of plants in our midst is of very great importance inasmuch as it provides us with medicinal agents of every description, not only sufficient for our own use but also for purposes of export.

(*b*) *Poisonous to livestock.*—The second important aspect of these plants is in connexion with poisoning of livestock and here, as compared with other countries, our knowledge is very meagre. In India, there are hundreds of plants that are intimately connected with the food supply of roughly 220 millions of the bovine population out of a total of about 730 millions in the whole world. The fodder supply for this livestock amounts to at least 33 million maunds daily (excluding the concentrates that are in use). Even in its present unsatisfactory condition, the cattle industry contributes approximately 10,000 million rupees to the annual agricultural income of 20,000 million rupees of this vast country. Unfortunately no figures are available of the loss suffered through poisoning with plants in India, but we believe these must be enormous. It may be interesting here to give the example of two states, Montana and Colorado in the United States of America which may give us some idea of the possible damage. In that area it has been computed that the loss caused to the livestock industry by plant poisoning is in the neighbourhood of 200 million dollars annually. This is a very large figure considering that the size and extent of these states, as compared with India, is less than one-sixth, and also considering the fact that the knowledge of the poisonous plants there is well advanced and preventive measures are in vogue.

Though the number of plants which have markedly poisonous properties is perhaps small compared with the total species included in the Indian flora, there are many which are of common occurrence and which no doubt produce serious losses by death or illness among sheep, cattle and other domestic animals. The toxic effects produced may be indicated by reduction in the yield of milk, the milk may become unpalatable through excretion in it of toxic products, or it may even become poisonous (e.g. in the case of nux-vomica) and thus become unfit for consumption. The flesh of the poisoned animals, with the exception of the part where the poison has been introduced (e.g., by arrow wound) generally remains edible, though the viscera, especially the excretory organs, have to be discarded.

It may be stated here that animals do not instinctively select toxic plants as forage, that all classes of livestock are not necessarily equally susceptible to the same poisonous plants, that not all poisonous plants are dangerous from their initial appearance up to maturity and that in some cases the animals do acquire a depraved appetite for harmful plants, especially when the fodder supply is scarce, a condition which is of frequent occurrence in many parts of India. The losses in many cases may be avoided by increasing our knowledge about these plants by a systematic study and by working out practical preventive measures.

Prevention.—The question arises as to what should be done to prevent poisoning by plants. The adage ' prevention is better than cure ' is applicable to the problem of plant poisoning with just as much force as in other spheres. Often cases are brought to notice when the symptoms have developed and the poison has already circulated in the blood stream and done irreparable damage to the system. Increased knowledge of the poisonous plants is the first step in this direction and this is sure to have an effect in decreasing fatalities among human beings and livestock. Keeping the animals away as far as possible from dangerous areas and exercising special care during periods of drought are likely to decrease the mortality amongst livestock. Eradication of poisonous plants is a difficult matter, involving an enormous amount of labour and capital, but wherever and whenever possible it should be resorted to. This depends upon the habits of the particular plant. Such plants may be annual, biennial or perennial herbs, or shrubs or trees. Annuals complete their life-cycle within one year; these should be pulled out or dug out before seeding. Biennials require two years to complete their life-cycle, growing one year, and flowering and fruiting in the second; these may be dealt with as the annuals. Perennial herbs last several years, not perishing normally after once flowering and fruiting; the above-ground portion dies each year, the root persisting. These are propagated both by the seeds and by the underground organs, such as tubers, rootstocks, bulbs, etc. and may be dug out if not deeply rooted. Shrubs are woody perennials and should be cut down or dug out. Cutting down of lower branches of trees within the reach of animals or children is advocated.

The indiscriminate importation of ornamental plants has recently increased the number of poisonous plants in India. Some of these do not find much competition in their adopted home and are spreading or are likely to spread in this country at an enormously rapid pace. The time perhaps is not yet ripe to agitate for a law prohibiting the importation of poisonous plants for gardens or to take measures to forbid the cultivation of those already introduced, but sooner or later it may have to be considered. In the meantime an appeal may be made to the good sense of the people to limit such practices as far as possible. The cuttings should not be disposed of in such a way as to be accessible to livestock.

The foodstuff dealers should make sure that adulteration is not practised either with poisonous plants or with plants whose properties are doubtful. Recent work in connexion with the causation of epidemic dropsy at the School of Tropical Medicine, has shown that in some epidemics mustard

oil adulterated with *katakar* oil from the seeds of *Argemone mexicana* Linn., the mexican poppy or *shialkata*, was the cause of the outbreak. Experimental work on human volunteers showed that food cooked in oil containing known quantities of argemone oil produced symptoms of gastro-intestinal irritation, oedema and cardiac involvement closely resembling those found in epidemic dropsy. The active principle present in this oil has a cumulative effect, and provided a sufficient quantity of the oil is consumed, symptoms appear even though the consumption of the argemone oil or incriminated mustard oil is stopped. From the evidence available it is clear that the adulteration of mustard oil with argemone oil may or may not be intentional on the part of those who grow mustard seeds or those who express or sell the oil. The plant *Argemone mexicana* grows abundantly and its seeds bear a superficial resemblance to the mustard seeds.

Food poisons.—In connexion with this group, the question of food poisons is of special significance and it will not be out of place to cite a few instances.

1. *Khesari dal, Lathyrus sativus* Linn., an important article of diet in man and animals, has been responsible for a large number of cases of poisoning under certain conditions in man, cattle, sheep, pigs, horses, pigeons, ducks, etc. Examples of lathyrism in man in the form of spastic paralysis are commonly seen every day in the streets of Calcutta and its toxic effects in horses and cattle are well known. Moderate amounts of this pulse can be taken with impunity. It is only if large amounts are taken, especially to the exclusion of other fodders or foods, that the untoward symptoms develop.

2. Grasses (*Gramineae*) form an important part of the food of animals. Some of these develop dangerously large quantities of hydrocyanic acid under certain climatic and soil conditions, especially at times of drought or when the plants are wilting, stunted or young. Unfortunately our knowledge of Indian grasses in this connexion is meagre and it is not possible to estimate the losses in livestock from this source. From some of the recent work done it would appear that quite a number of these grasses may be dangerous under conditions that still need to be investigated in India. The examples are *jowar* (*Sorghum vulgare* Pers.), the Indian millet, which is largely cultivated in this country as fodder for cattle and also for human food. It has caused serious outbreaks of poisoning among livestock when wilted or stunted under drought conditions. *Sorghum halepense* Pers., a tall perennial grass with creeping rhizomes and numerous suckers, known as Johnson grass, grows all over India under the name of *baru* in Hindi and *kala-mucha* in Bengali. It has been responsible for serious losses among livestock during recent years in the N.-W. F. Province where it is known as *dadam*. It has been stated that the amount of hydrocyanic acid in these plants decreases with the age of the plant but never entirely disappears. The points to be remembered about these grasses are that they are dangerous during wilting and under conditions of drought, that younger and more succulent ones are often more likely to contain lethal doses of hydrocyanic acid and, that, if well dried, these plants are generally not dangerous. The toxicity in the case of cyanogenetic compounds depends on the quantities of hydrocyanic acid liberated, and according to the amount and speed at which they are eaten. Often such large quantities are given that the animal

will die before any veterinary aid can be given. The only remedy is prevention. The problem of poisonous grasses is of great economic importance in certain parts of India where rains often fail and drought conditions prevail. In the recent famine in the Hissar district of the Punjab there is little doubt that in addition to ravages caused by scarcity of food, the livestock must have suffered enormously from this source.

(3) The linseed plant, *Linum usitatissimum* Linn., contains a cyanogenetic glucoside, the maximum amount of which is reached very early in the development of the plant and finally disappears, except in the seed, which still contains small quantities. An oil is expressed from the seeds and the remaining cakes are used to feed livestock. Cases of poisoning have been frequently reported amongst animals feeding on this plant. It is unsafe to feed the cattle on the immature plant, especially when it is wilted. The cake after extraction of the oil should be treated with boiling water to destroy the enzyme responsible for liberating hydrocyanic acid from the glucoside, and should not be soaked in cold water overnight. It should be given only in small quantities at a time.

(5) The mustard cake which is fed to cattle after the extraction of oil may produce chronic irritant poisoning, colic, lassitude, etc., if fed in large amounts and over prolonged periods, on account of the liberation of an essential oil by the action of an enzyme on the glucoside contained therein. The danger seems to be less in the case of *sarson* seeds than in the case of *rai* or black mustard. If boiling water is poured over the crushed cakes the enzymes are destroyed and the cakes become safe.

(6) Several members of the cucumber family (*Cucurbitaceae*) are edible but bitter varieties are occasionally met with. The latter have a strong purgative action and should be discarded. Incidentally it may be remarked that most of the wild members of the family are toxic. Colocynth which is a powerful intestinal irritant is a familiar example. The bitter members of this family have more or less a similar action.

(7) The leaf-blades of rhubarb (*Rheum* sp.) may give rise to nausea, violent vomiting, purging and abortion on account of having a high percentage of oxalic acid or oxalates in them, while no such cases have been reported from eating the leaf-stalk. The fresh leaves of beet-root (*Beta* sp.) have also produced poisoning in livestock on account of the presence of oxalates.

(8) The potato, *Solanum tuberosum* Linn., when sprouting, produces dangerously large quantities of the toxic alkaloid, solanine, and must be thrown away.

(9) Certain plants, such as buck-wheat (*Fagopyrum esculentum* Moench) which is largely cultivated for human and animal consumption, under certain conditions not yet fully understood, become toxic and give rise to inflammatory swellings of the face, eyelids and ears.

ii. Plants poisonous to insects and fishes

(*a*) *Insecticidal and insect repellent plants.*—The second group of these plants are those which are poisonous to insects and pests which do incalculable harm to man in many ways. The finding of cheap insecticides for

the diverse needs of agriculture, destruction of household pests, prevention of vectors of such diseases as malaria and many others borne by insects is a very important problem and one to which a good deal of attention has been paid in recent years. It would be no great exaggeration to say that insects have been responsible for more loss of life and destruction of property than that caused by wars, floods, earthquakes, fires and famines in the history of man. Advance in civilization is producing conditions suitable for insect multiplication in many places, in spite of all efforts to the contrary. On a moderate computation the annual loss caused to India through insect pests has been put at 2,000 millions of rupees and over a million and a half of human lives. An effective defence against these enemies of social and economic progress will materially reduce this enormous wastage and facilitate national development. One of the necessities for combating this menace is to find cheap and effective insecticides, commensurate with the means of the great masses in India whose economic condition is very low. At the present time our knowledge of plants bearing insecticidal properties in this country is very meagre indeed. A thorough enquiry into this aspect of poisonous plants is, therefore, of prime importance to the country. For several reasons vegetable insecticides are preferable to the mineral ones, such as arsenicals, copper compounds, mineral oils, etc. Those from vegetable sources are undoubtedly less deleterious to human beings and other warm-blooded animals generally and they are also less harmful from the point of view of agriculture. Most of the mineral insecticides at the present time are imported from foreign countries and are therefore expensive. So far as the insecticides from the plant kingdom are concerned, so little is known in this country that we have to depend on those growing in other countries. The larger the number of effective insecticides we discover from among our poisonous plants the greater will be the chances of their being brought into extensive use by the people for medical, veterinary, agricultural and household purposes.

Of the vegetable insecticides of proved value may be mentioned *Chrysanthemum* (*pyrethrum*), *Derris* (tuba-root), *Nicotiana* (tobacco), *Tephrosia*, *Picrasma* (quassia), *Delphinium* (larkspur), *Veratrum*, etc. Attemps are now being made to cultivate *pyrethrum* in India on account of its effectiveness in destroying insects and mosquito larvae. *Derris elliptica* Benth. is found to a very limited extent in India, but several allied species found here are worth investigating. Of these *Derris ferruginea* Benth. has been recently shown to contain rotenone and may prove to be a good insecticide. Tobacco is largely cultivated in India. *Tephrosia vogelli* Hook. *f.* has been shown in foreign countries to be an efficient insecticide for fleas, lice and ticks and it has been suggested that it may be used as a cheap commercial dip for cattle. Some of the other species of *Tephrosia* are also stated to have insecticidal properties, but several of the Indian species although met with in abundance remain uninvestigated. Indian species of *Picrasma* also need investigation and we have been informed that powdered young leaves and twigs of *P. napaulensis* Benn. are used to kill mosquito larvae in Assam. Several Indian species of *Delphinium* are already used for destroying maggots in wounds and may be potential insecticides. Furthermore it has been stated that the alkaloid cytisine is an important constituent of the Persian and Australian

insect powder. This alkaloid, which resembles nicotine in its action, has been found in at least six genera of which *Euchresta* and *Sophora* are represented in India.

Hackett, Russell and others (Bulletin of the Health Organisation, League of Nations, 1938) discuss the naturalistic methods in practice for the control of mosquito larvae and refer to the role of the plant kingdom for this purpose. It is stated that pollution by vegetable matter in the form of industrial wastes has often been tried with success as an anti-malarial measure. In a case reported from the Philippines bagasse from sugarcane mills seemed to be keeping a stream free from *flavirostris* ; the refuse from the Government Sisal Experiment Station is alleged to have a similar action, while the numerous large pits used for macerating *canepa* hemp in Italy do not breed anophelines. Stagnant pools, such as engineering borrow-pits into which green cut vegetation has been thrown, are stated to breed culicines only, anophelines being inhibited. The lethal effect of a fortnight-old brew of cut grass is said to be remarkable. The extention of this method in the form of ' herbage-packing ' to shallow, small-volume, running channels has been advocated by Williamson and the present authors. They think that the effect of this is not mechanical but biological, and consider that the use of green cut vegetation is very important, for dry straw will only result in a hay infusion favourable to larval growth. It is not every plant, however, that is suitable in the case of running water. According to these authors, ' The best so far found in India are *Cleistanthus* species and *Holorrhena antidysenterica* (sic). The first of these are fish poisons ; the latter contains several alkaloids.'

We are confident, however, that many more plants, mentioned in the synopsis at the end of this article would be found equally good or even better for this purpose, but the piscicidal plants in connexion with this must be employed with caution, since it is inadvisable to use them if the water contains fishes, or drains into tanks or reservoirs containing them.

There are also a number of plants which are utilized as insect repellents, e.g. roots of costus, *Saussurea lappa* C. B. Clarke, essential oil from *Eucalyptus globulus* Labill., leaves of *neem*, *Azadirachta indica* Juss., and of patchouli, *Pogostemon heyneanus* Benth., etc. The investigation of vegetable insecticides and insect repellents from among the vast potential resources existing in this country will repay scrutiny.

(*b*) *Plants poisonous to fish.*—That there are many plants in the Indian flora which have deleterious effect on fish is well known. Wholesale poisoning of fish in ponds, streams and pools by means of these plants is very uneconomical and is not allowed in any civilized country, but cases are known where such plants have come into contact with water and enormous numbers of fish have died as a result. This aspect of these plants, though not perhaps so important as the other, cannot be entirely left out of consideration in the study of poisonous plants. The list of plants growing in India having a poisonous action on fish is very long and a large number of them have been referred to in the book, *Indigenous Drugs of India* ; lately considerable additions have been made which may be of interest to those wanting further information. This group is of importance, as some of the insecticides are

also piscicides and *vice versa* and a systematic investigation of this group may lead to the discovery of effective insecticides, which is the crying need of this country at the present time.

We have briefly referred to the toxicological aspects of plants growing in India in a very general way. A good deal of work has been done in connexion with poisonous plants in Europe, America, South Africa and other countries, yet little or no systematic work has so far been attempted in India. The senior author was deeply impressed with this regrettable state of affairs when he took up work on Indian indigenous drugs nearly twenty years ago. Unfortunately it was not possible to start even a general survey of this group till a few years ago when the Imperial Council of Agricultural Research gave a grant and added a botanical section to the already-existing unit composed of chemists and pharmacologists paid by funds generously given by the Indian Research Fund Association twelve years ago. With this team of enthusiastic workers a beginning was made. To start with, three thousand circulars were sent out to the forest, veterinary, medical and agriculture departments of different provinces, to universities and to individual workers all over India. Different parts of the country were visited and first-hand information from all local sources by extensive investigations carried out in the field was obtained. All the existing herbaria were scrutinized, the information thus collected was analysed and a monograph on the subject of Poisonous Plants of India is now in the course of preparation. A list of nearly 700 plants reputed to be poisonous to man, livestock, insects, fish, etc., has been prepared which is by far the largest so far collected in this country. In the case of many plants, poisonous properties are suspected but have not been substantiated by chemical analysis and pharmacological experimentation. This is now being done so far as is possible with the resources at our disposal and preliminary chemical examinations of many important plants are being made. A thorough and comprehensive study of all these plants is the work of many years, perhaps of several generations. In the present work we are getting together all available information, botanical, chemical and pharmacological, in connexion with poisonous plants growing in India together with all references in the literature. The monograph, when completed, will serve as a basis for future work on these plants, the importance of which from an economic point of view cannot be overrated.

A conspectus of poisonous Phanerogams (including food poisons) growing in India, either in a state of nature or under cultivation, is appended. This will give some idea as to the ground covered in our recent investigations and the scope of the monograph, which will be profusely illustrated. The plants have been dealt with according to Bentham and Hooker's system of classification and the important active principles occurring in each family have been given and the main effects produced have been briefly discussed. Special attention has been paid to the nomenclature of plants and adherence to the International Rules has caused, unfortunately, several departures from the names used in *The Flora of British India*. A large number of plants, as described in that monumental work, are differently understood or are differently named or spelt by modern botanists. Some of these changes have now become well known in India. In this brief article, we have not attempted

to point out all departures from *The Flora of British India*, but have only indicated some of the less-established changes in this direction which were considered necessary.

We take the opportunity of expressing our gratitude to the Imperial Council of Agricultural Research for the generous grant to this inquiry and to all our colleagues of the indigenous drugs inquiry and of the Calcutta School of Tropical Medicine, the forest, agricultural, veterinary and medical departments of various provinces and Indian states, the Superintendent, Royal Botanic Gardens, Sibpur, the Botanical Survey of India, the chemical examiners, universities, and other individuals who have helped us in this important work, both in the field and in the laboratories and herbaria.

Poisonous Plants of India

Families and active principles	Names of plants	General remarks
1. *Ranunculaceae* (Buttercup Family) Anemonin, aconitin, indaconitin, pseudaconitin, adonidin, delphinine, staphysagroine, cyanogenetic glucosides, essential oils, saponins, etc.	1. *Aconitum balfourii* Stapf, *A. chasmanthum* Stapf *ex* Holmes, *A. deinorrhizum* Stapf, *A. elwesii* Stapf, *A. falconeri* Stapf, *A. ferox* Wall. *ex* Seringe, *A. laciniatum* Stapf, *A. laeve* Royle, *A. lethale* Griff., *A. luridum* Hk. *f.* & T., *A. moschatum* Stapf, *A. soongaricum* Stapf, *A. spicatum* Stapf, *A. violaceum* Jacq.	Cardiac depressant and nerve poison; cause deaths among livestock; also used as arrow poison
	2. *Actaea spicata* Linn.	Acrid and poisonous; deaths among horses reported
	3. *Adonis aestivalis* Linn., *A. chrysocyathus* H. *f.* & T.	Poisonous to animals; heart poison
	4. *Anemone obtusiloba* D. Don.	Vesicant; taken internally produces vomiting and purging, drying alters properties
	5. *Aquilegia vulgaris* Linn.	Poisonous
	6. *Caltha palustris* Linn.	Acrid and poisonous; deaths among horses reported
	7. *Cimicifuga foetida* Linn.	Heart depressant; insect repellent
	8. *Clematis gouriana* Roxb., *C. graveolens* Lindl., *C. napaulensis* DC., *C. orientalis* Linn., *C. triloba* Heyne, *C. wightiana* Wall.	Blistering, properties altered by drying

	9. *Delphinium brunonianum* Royle, *D. caeruleum* Jacq., *D. elatum* Linn., *D. vestitum* Wall.	Cardiac and respiratory depressants; acrid taste, insecticidal, poisonous to animals
	10. *Nigella sativa* Linn.	Abortive in larger doses
	11. *Paeonia emodi* Wall.	Narcotic
	12. *Ranunculus arvensis* Linn., *R. falcatus* Linn., *R. laetus* Wall., *R. lingua* Linn., *R. pensylvanicus* Linn. *f.*, *R. sceleratus* Linn.	Vesicant and poisonous to livestock when fresh; drying alters properties
2. *Magnoliaceae* (Magnolia and Champa Family) Shikimin, illicin, essential oils	1. *Illicium griffithii* Hk. *f.* & T., *I. religiosum* Sieb. & Zucc.	Star anise of China (*I. verum* Hook. *f.*) imported into India sometimes adulterated with *I. religiosum*; has produced deaths. The latter is respiratory and cardiac poison. Indian *I. griffithii* also referred to as poisonous
3. *Annenaceae* (Custard apple Family) Resin, alkaloid, etc.	1. *Annona reticulata* Linn., *A. squamosa* Linn.	Seeds intensely irritant to conjunctiva; locally used as abortifacient, insecticidal; roots drastic purgative
4. *Menispermaceae* (Moonseed Family)	1. *Anamirta cocculus* (Linn.) W. & A.	Convulsant poison; insecticide; used to poison fish and cattle
Picrotoxin, saponins	2. *Pachygone ovata* (Poir.) Miers	Insecticide, piscicide
5. *Berberidaceae* (Barberry Family)	1. *Berberis aristata* DC. (and probably few more species)	Poisonous to lower animals; piscicide
Berberine, podophyllum resin	2. *Podophyllum hexandrum* Royle (= *P. emodi* Wall. *ex* Hk. *f.* et T.).	Drastic purgative, resin irritant to mucous membranes

Families and active principles	Names of plants	General remarks
6. *Papaveraceae* (Poppy Family)	1. *Argemone mexicana* Linn.	Oil occasionally mixed with mustard oil; adulterated mustard oil experimentally produced condition resembling epidemic dropsy
Morphine, codeine, protopine, thebaine, papaverine, narcotine, narceine, etc.	2. *Meconopsis aculeata* Royle, *M. napaulensis* DC.	Roots narcotic
	3. *Papaver dubium* Linn., *P. nudicaule* Linn., *P. rhoeas* Linn., *P. somniferum* Linn.	All species yield opium more or less, *P. somniferum* the chief source; opium used for suicidal purposes
7. *Cruciferae* (Mustard Family) Glucosides on contact with water produce vesicant essential oils	1. *Brassica cernua* (Thunb.) Forbes et Hemsl., *B. integrifolia* (West) O. E. Schulz, *B. juncea* (Linn.) Czernjaew et Cosson (*rai*); *B. napus* Linn. with four varieties (*toria, sarson*); *B. nigra* (Linn.) Koch (black mustard)	Vesicant; mustard cakes if fed in large amounts and over prolonged periods harmful to cattle, *sarson* cake safest, mixture with *rai* or black or white mustard dangerous
	2. *Lepidium draba* Linn.	Fish poison
	3. *Sinapis alba* Linn. (white mustard)	Discussed under *Brassica*
8. *Capparidaceae* (Caper Family)	1. *Capparis aphylla* Roth	Vesicant
Essential oils	2. *Cleome felina* Linn. *f.*, *C. viscosa* Linn.	Vesicant
	3. *Gynandropsis gynandra* (Linn.) Merr. (*G. pentaphylla* DC.).	Insecticide, piscicide, vesicant

9. *Bixaceae* (Chaulmoogra Family)	1. *Gynocardia odorata* R. Br.	Fruit piscicide
Cyanogenetic glucoside; chaulmoogra oil	2. *Hydnocarpus kurzii* (King) Warb. (=*Taraktogenos kurzii* King), *H. laurifolia* (Dennst.) Sleumer (=*H. wightiana* Bl.)	Fruit piscicide. Seed oil gastro-intestinal irritant
10. *Polygalaceae* (Milkwort Family)	1. *Polygala chinensis* Linn., *P. crotalarioides* Buch.—Ham., *P. telephioides* Willd.	Expectorant, emetic, acrid
Saponins		
11. *Caryophyllaceae* (Carnation Family)	1. *Saponaria vaccaria* Linn., and probably some others of the family	Acrid; toxicity partially removed by boiling
Saponins		
12. *Hypericaceae* St. John's-wort Family Balsamic resinous juice	1. *Hypericum perforatum* Linn.	Poisonous to animals, especially horses if taken in excess, usually however not eaten
13. *Guttiferae* (Gamboge Family)	1. *Calophyllum inophyllum* Linn.	Fish poison
Gum resins	2. *Garcinia morella* Desrouss and probably others	Gum resin violent gastro-intestinal irritant
14. *Ternstroemiaceae* (Tea Family)	1. *Thea sinensis* Linn.	Excessive indulgence harmful
Caffeine, theophylline		
15. *Malvaceae* (Cotton Family)	1. *Gossypium* species	Root bark emmenagogue and used as abortifacient, occasional harmful effects of cotton seed cake on animals reported
Gossypol, resin, ephedrine, pseudo-ephedrine		

Families and active principles	Names of plants	General remarks
15. *Malvaceae*—contd.		
	2. *Malva parviflora* Linn.	Narcotic effects on animals reported
	3. *Sida rhombifolia* Linn.	Ripe capsules reported fatal to fowls
16. *Linaceae* (Flax Family)	1. *Erythroxylum coca* Lam.	Central nervous stimulant; sensory nerve endings—paralysant; addiction harmful
Cyanogenetic compounds; cocaine	2. *Linum usitatissimum* Linn.	Young plants produced deaths in animals; sometimes seed cake also harmful
17. *Zygophyllaceae* (Bean-caper and Guaicum Family)	1. *Peganum harmala* Linn.	Insecticide, narcotic, nauseant and emetic. Used as abortifacient, protoplasmic poison; paralyses skeletal and cardiac muscles of frogs
Harmine, harmaline, harmalol, peganine, essential oils, saponins, resins	2. *Tribulus terrestris* Linn.	Causes geeldikkop (dikgeel) in South Africa in small stock; characterized by oedema of head, fever and jaundice
18. *Rutaceae* (Rue Family)	1. *Acronychia pedunculata* (Linn.) Miq. (=*A. laurifolia* Bl.)	Fish poison
Essential oils, rutin, skimmianine, saponins, resins, etc.	2. *Ruta graveolens* Linn. var. *angustifolia* Hk. *f.*, *R. tuberculata* Forsk.	Acro-narcotic poison, rubefacient; oil and herb frequently used to produce criminal abortion
	3. *Skimmia laureola* Sieb. & Zucc. *ex*-Walp.	Reported poisonous to sheep and goats

	4. *Zanthoxylum alatum* Roxb. (probably some more species)	Fish poison
19. *Simarubaceae* (Bitter-bark Family)	1. *Ailanthus altissima* (Mill.) Swingle (=*A. glandulosa* Desf.)	Nauseant, nervous system depressant, accumulation of its leaves in well water reported to produce chronic gastritis
Essential oils, saponins, resins, bitter substances	2. *Balanites roxburghii* Planch.	Fish poison, purgative
	3. *Brucea sumatrana* Roxb.	Seeds produce nausea, vomiting, abdominal pain and purging
	4. *Picrasma napalensis* Benn.	Stated to be used as larvicide in Sikkim
20. *Meliaceae* (Neem & mahogany Family)	1. *Azadirachta indica* A. Juss	Parasiticidal, leaves used as insect repellent
Bitter substances, bitter oil, saponins	2. *Melia azedarach* Linn.	Berries especially poisonous to man and animals; narcotic and gastro-intestinal irritant
	3. *Walsura piscidia* Roxb.	Dangerous emmenagogue, violent emetic, largely used as a fish poison
21. *Celastraceae* (Spindle-tree Family)	1. *Elaeodendron glaucum* Pers.	Emetic; overdoses fatal
Alkaloid, essential oil, resin		
22. *Sapindaceae* (Soap-nut Family)	1. *Cardiospermum halicacabum* Linn.	Leaves emetic and rubefacient
Saponins, cyanogenetic compounds	2. *Dodonaea viscosa* Linn.	Fish poison; deleterious to camels

Families and active principles	Names of plants	General remarks
22. *Sapindaceae*—contd.	3. *Harpullia cupanioides* Roxb.	Fish poison
	4. *Melianthus major* Linn.	Produces acute diarrhoea, salivation and colic ; honey from flowers stated to be poisonous
	5. *Sapindus mukorossi* Gaertn., *S. trifoliatus* Linn.	Fish poison, emetic, purgative ; used for procuring abortion
	6. *Schleichera oleosa* (Lour.) Merr. (=*S. trijuga* Willd.).	Oil occasionally mixed with mustard oil or ghee produces irritant poisoning ; seeds used as insecticide
23. *Anacardiaceae* (Cashew & mango Family)	1. *Anacardium occidentale* Linn.	Pericarp contains powerfully vesicant juice, used to preserve floors, wood, books, etc. from white ants ; tar from bark also vesicant
Toxic phenolic compounds, toxic resin	2. *Holigarna arnottiana* Hook. *f.*, *H. ferruginea* March, *H. grahamii* (wight) Hook. *f.*, *H. longifolia* Buch.-Ham. *ex* Roxb.	Juice vesicant although not equally powerful in all species
	3. *Rhus insignis* Hook. *f.*, *R. punjabensis* J. L. Stewart, *R. succedanea* Linn., *R. wallichii* Hook. *f.*	Dreaded by local people ; even smoke from burning wood dreaded ; juice vesicant
	4. *Semecarpus anacardium* Linn. *f.*, *S. travancoricus* Bedd.	Pericarp contains vesicant juice. Sometimes used locally as abortifacient
24. *Coriariaceae* (Coriaria Family)	1. *Coriaria nepalensis* Wall.	Stated to be narcotic ; foreign species very poisonous acting like picrotoxin and producing convulsions
Coriamyrtin, tutin in foreign species		

25. *Moringaceae* **(Horse-radish Family)** **Essential oils, alkaloid, moringine, moringinine**	1. *Moringa oleifera* Lamk. (=*M. pterygosperma* Gaertn)	Fresh root bark vesicant, used to procure abortion. Moringinine acts on the sympathetic nervous system
26. *Leguminosae* **(Pea Family)** **Alkaloids ; glucosides, saponins, cyanogenetic compounds, rotenone, toxic albumin, bitter substances, globulins**	1. *Abrus precatorius* Linn.	Specially blood poison, used to poison cattle and to procure abortion
	2. *Acacia pennata* Willd.	Fish poison
	3. *Albizzia procera* Benth.	Fish poison
	4. *Butea monosperma* (Lam.) O. Ktze. (=*B. frondosa* Koen. *ex*-Roxb.)	Seeds insecticide ; painful if taken internally
	5. *Caesalpinia nuga* Ait	Fish poison
	6. *Canavalia virosa* W. & A. (*C. ensiformis* DC. var. *Virosa* Baker)	Fruit stated to be poisonous
	7. *Cassia absus* Linn., *C. acutifolia* Delile, *C. alata* Linn., *C. angustifolia* Vahl, *C. fistula* Linn., *C. obovata* Collad	Purgative ; irritant in large doses, *C. absus* seeds dangerous application to eyes. *C. alata* fish poison
	8. *Clitoria ternatea* Linn.	Roots powerful cathartic like Jalap ; not a safe medicine
	9. *Cytisus scoparius* Link.	Plants not eaten by cattle ; emetic and cathartic
	10. *Dalbergia stipulacea* Roxb.	Fish poison
	11. *Derris elliptica* Benth., *D. scandens* Benth., *D. uliginosa* Benth., (Possibly *D. ferruginea* Benth.)	Fish poison. *D. elliptica* is insecticidal

Families and active principles	Names of plants	General remarks
26. *Leguminosae*—contd.	12. *Entada phaseoloides* (Linn.) Merr. (=*E. scandens* Benth.)	Fish poison
	13. *Lathyrus aphaca* Linn., *L. sativus* Linn.	Food and fodder. *L. sativus* if taken in larger amounts and over prolonged period produces lathyrism in men and animals. Ripe seeds of *L. aphaca* stated to be narcotic in excess
	14. *Melilotus alba* Desr.	Stated to be poisonous to cattle
	15. *Milletia auriculata* Baker, *M. pachycarpa* Benth., *M. piscidia* Wight	Fish poison; *M. auriculata* is an insecticide
	16. *Mundulea suberosa* Benth	Fish poison
	17. *Ougenia dalbergioides* Benth	Fish poison
	18. *Phaseolus lunatus* Linn.	Coloured variety sometimes exhibits poisonous properties if eaten
	19. *Pithecellobium bigeminum* Mart.	Fish poison. Seeds stated to be eaten in Burma but sometimes produce disastrous results
	20. *Pongamia pinnata* (Linn.) Merr. (=*P. glabra* Vent.)	Piscicide and insecticide
	21. *Sophora mollis* R. Grah., and Var. *hydaspidis* Baker, *S. tomentosa* Linn.	Seeds of *S. mollis* insecticidal, leaves of *S. tomentosa* powerfully emetic and cathartic in large doses

	22. *Tephrosia candida* Linn., *T. purpurea* Pers. (F. B. I. in part)	Fish poison. Some foreign species are insecticides. Species of *Tephrosia* in India likely to prove of value as insecticides
	23. *Trifolium repens* Linn.	Highly prized fodder in Europe. Very suspicious in Himalayas where poisoning reported in horses
	24. *Vicia sativa* Linn.	Suspected to cause lathyrism—see *Lathyrus sativa*
27. *Rosaceae* (Rose Family)		
Cyanogenetic glucosides, phloridzin	1. *Prunus amygdalus* Batsch. (bitter variety), *P. armeniaca* Linn., (bitter variety), *P. avium* Linn., *P. cerasus* Linn., *P. mahaleb* Linn., *P. padus* Linn., *P. persica* Stokes., *P. puddum* Roxb., *P. undulata* Buch.—Ham.	Seeds poisonous, leaves of many said to be dangerous to livestock when wilted ; harmless when on the plant, suspicious when dried
	2. *Pygeum gardneri* Hook. *f.*	Seeds fish poison
	3. *Pyrus aucuparia* Linn., *P. malus* Linn.	Bark of *P. aucuparia* irritant to the alimentary tract ; wilting leaves of other occasionally poisonous to animals browsing upon them
	4. *Rubus moluccanous* Gaertn.	Leaves reported as powerful emmenagogue and abortifacient
28. *Crassulaceae* (Life-plant Family)		
Glucosides—in foreign species	1. *Kalanchoe spathulata* DC.	Expressed juice of bitter variety drastic purgative ; poisonous to goats, not eaten by cattle ; leaves said to be insecticide
29. *Droseraceae* (Sundew Family)		
	1. *Drosera peltata* Sm. var. *lunata* Clarke, *D. spathulata* Labill. (*D. burmanni* Vahl)	Rubefacient. Some Australian species reported injurious to sheep

Families and active principles	Names of plants	General remarks
30. *Combretaceae* (Myrobolan Family) Tannins	1. *Terminalia bellerica* Roxb., *T. chebula* Retz.	*T. bellerica* reported fish poison ; kernel stated to be poisonous and cases reported where narcotism followed nausea and vomiting, evidence however conflicting. Some varieties of *T. chebula* drastic purgative
31. *Myrtaceae* (Myrtle and *jamun* Family) Saponins, essential oils, tannins	1. *Barringtonia acutangula* Gaertn., *B. asiatica* Kurz. (=*B. speciosa* Forst.), *B. racemosa* Bl.	Fish poisons
	2. *Careya arborea* Roxb.	Fish poison, inner bark rubbed on shoes keeps off leeches
	3. *Eucalyptus globulus* Labill.	Essential oil an important ingredient of insecticides ; internally gastro-intestinal irritant
	4. *Melaleuca leucadendron* Linn.	Essential oil is an irritant and a mosquito repellent
32. *Lythraceae* (Henna and pomegranate Family) Acrid principle	1. *Ammania baccifera* Linn., *A. senegalensis* Lamk.	Acrid, vesicant ; internally cause great pain
	2. *Lagerstroemia indica* Linn., *L. speciosa* (Linn.) Pers. (=*L. flos-regineae* Retz.)	Bark and leaves purgative ; seeds of former narcotic
33. *Samydaceae* (Cascaria Family)	1. *Cascaria graveolens* Dalz., *C. tomentosa* Roxb.	Pounded fruit used as a fish poison

34. *Caricaceae* **(Papaw Family)** **Carpaine, carposide, caricin in seeds yielding essential oil on hydrolysis ; papain**	1. *Carica papaya* Linn	Seeds believed to be powerfully emmenagogue and used as abortifacient. The juice of unripe fruit acrid or even vesicant
35. *Passifloraceae* **(Passion-flower Family)** **Hydrocyanic acid, saponins**	1. *Adenia (Modecca) palmata* Engl., *A. wightiana* Engl.	Roots and fruits poisonous. Deaths from fruits of *A. palmata* reported
36. *Cucurbitaceae* **(Cucumber Family)** **Bitter substances, such as colocynthin, alkaloids, glucosides, saponins**	1. *Citrullus colocynthis* Schrad, *C. vulgaris* Schrad (bitter variety)	Fruit purgative ; *C. colocynthis* a drastic purgative has produced fatal results, dust when dry very irritating to eyes and nostrils
	2. *Corallocarpus epigaeus* Benth. & Hook. *f.*	Fruit drastic purgative
	3. *Cucumis sativus* Linn. (bitter variety), *C. trigonus* Roxb.	Fruit purgative, *C. trigonus* excessively so
	4. *Lagenaria vulgaris* Seringe (Wild variety)	Drastic purgative, case reported where beer kept in bottle gourd produced poisoning
	5. *Luffa acutangula* Roxb. var. *amara* C. B. Clarke, *L. aegyptiaca* Mill. *ex*-Hook. *f.* (wild variety), *L. echinata* Roxb.	Fruit of *L. acutangula* var. *amara* violently emetic and purgative, is not eaten ; others also purgative
	6. *Momordica balsamina* Linn., *M. charantia* Linn., *M. tuberosa* Cogn. (=*M. cymbalaria* Fenzl)	Fruit of *M. balsamina* fatal to dogs. Death from violent vomiting and purging from juice of plant. *M. charantia*, roots used as abortifacient. Decoction of roots of *M. tuberosa* used as abortifacient

Families and active principles	Names of plants	General remarks
36. *Cucurbitaceae*—contd.	7. *Trichosanthes bracteata* Voigt (=*T. palmata* Roxb.), *T. cucumerina* Linn., *T. dioica* Roxb.	Root powerful cathartic. Fruit of *T. cucumeriana* never eaten, because of powerful cathartic action. Fruit of *T. bracteata* used as cattle poison and to destroy crows
	8. *Zanonia indica* Linn.	Fruit very acrid and cathartic
37. *Begoniaceae* (Begonia Family)	1. *Begonia rex* Putzeys	Juice poisonous to leeches
38. *Ficoideae*	1. *Trianthema portulacastrum* Linn. (*T. monogyna* Linn.), *T. pentandra* Linn.	Roots irritant and cathartic. Leaves and stems used as pot herb but occasionally said to produce paralysis and diarrhoea
39. *Umbelliferae* (Carrot and coriander Family)	1. *Apium graveolens* Linn.	Seeds irritant, poison in overdoses
Essentia oils, cicutoxin, cicutoxinin, vellerin	2. *Centella asiatica* (Linn.) Urb. (= *Hydrocotyle asciatica* Linn.).	Stupefying narcotic in larger doses; a cumulative poison
	3. *Cicuta virosa* Linn.	Cause of extensive poisoning in Europe, the active principle belongs to picrotoxin in group of poisons which are convulsant
	4. *Daucus carota* Linn.	Seeds used for procuring abortion, tuberous roots eaten
	5. *Hydrocotyle javanica* Thunb.	Stated to be a fish poison

40. *Araliaceae* **(Ivy and Panax Family)** Resin, α—hederin saponin	1. *Hedera helix* Linn.	Decoction of leaves used to kill lice; other poisonous properties also assigned
41. *Caprifoliaceae* **(Honey-suckle Family)** Sambucine, cyanogenetic glucoside, sambunigrin, bitter substances, resin (cathartic)	1. *Sambucus ebulus* Linn., *S. nigra* Linn.	Strongly purgative. *S. ebulus* has foetid smell when bruised, is not eaten by cattle; poisoning amongst boys and fowls reported
42. *Rubiaceae* **(Madder and coffee Family)**	1. *Adina cordifolia* Benth. & Hook. *f.*	Juice used as insecticide
Quinine, quinidine, cinchonine, cinchonidine, caffeine, emetine, cephaeline, ipecacuanhin, essential oils, saponins	2. *Cinchona calisaya* Wedd. and var. *ledgeriana* Howard, *C. officinalis* Linn. *f.*, *C. succirubra* Pavon.	Source of cinchona alkaloids, general protoplasmic poison and parasiticide; plants fish poisons
	3. *Coffea arabica* Linn.	Excessive indulgence harmful, chronic poisoning
	4. *Psychotria ipecacuanha* Stokes	Emetic and irritant and cardiac depressant
	5. *Randia dumetorun* Lamk., *R. uliginosa* DC.	Fish poisons; *R. dumetorum* used to preserve grain from attacks of insects, used as abortifacient
43. *Compositae* **(Sun-flower Family)**		
Essential oils, artemisin, santonin, bitter substances (absinthin, lactucin, etc.), saponins, resin, senecio, alkaloids, xanthostrumarin, pyrethrins	1. *Anthemis cotula* Linn.	Undesirable food for livestock; acrid and vesicant
	2. *Artemisia absinthium* Linn., *A. maritima* Linn., *A. vulgaris* Linn.	Essential oil from *A. absinthium* violent narcotic poison producing convulsions; *A. maritima* irritant poison in large doses, fatal cases reported; *A. vulgaris* produces epileptiform spasms, also reported fish poison

Families and active principles	Names of plants	General remarks
43. *Compositae*—contd.	3. *Centhratherum anthelminticum* O. Ktze (=*Vernonia anthelmintica* Willd.)	Used as insecticide and insect repellent
	4. *Chrysanthemum cinerariifolium* Vis. *C. coccineum* Willd. (*C. roseum* Adam.)	Reputed insecticides
	5. *Erigeron canadensis* Linn.	Irritant
	6. *Eupatorium odoratum* Linn.	Stated fish poison ; *U. urticifolium* L. *f.* of foreign countries produces acidosis and trembles in sheep and cattle
	7. *Gnaphalium luteo-album* Linn.	Suspected of causing livestock-poisoning in South Africa
	8. *Inula graveolens* Desf.	Suspected poisonous to livestock
	9. *Lactuca tatarica* C. A. Meyer, var. *tibetica* C. B. Clarke	Occasionally browsed by sheep ; sometimes injurious
	10. *Saussurea lappa* C. B. Clarke	Roots used against insects
	11. *Senecio* species (*S. vulgaris* Linn. introduced plant)	Important genus, worth study in India ; ragwort poisoning due to several species well known in foreign countries ; various species produce hepatic cirrhosis
	12. *Sphaeranthus indicus* Linn.	Fish poison
	13. *Xanthium strumarium* Linn.	Reported poisonous to cattle and pigs in America and Australia

44. *Campanulaceae* (Bell-flower Family) Alkaloids	1. *Lobelia excelsa* Leschen., *L. nicotianifolia* Heyne	Irritants to nose, death reported in man, action like nicotine, except more burning pain in the stomach, used as substitute for *datura*
45. *Ericaceae* (Rhododendron Family) Andromedotoxin, ericolin, essential oils	1. *Gaultheria fragrantissima* Wall.	Irritant poison ; deaths reported from use as abortifacient
	2. *Pieris ovalifolia* D. Don.	Poisonous to goats ; insecticide
	3. *Rhododendron anthopogon* D. Don., *R. arboreum* Sm., *R. barbatum* Wall., *R. campanulatum* D. Don., *R. cinnabarinum* Hook. *f.*, *R. falconeri* Hook. *f.*, *R. setosum* D. Don.	Probably all poisonous to stock ; some reported fish poisons ; honey from some reported poisonous
46. *Plumbaginaceae*— (Plumbago Family) Plumbagin	1. *Plumbago indica* Linn. (=*P. zeylanica* Linn.,) *P. rosea* Linn.	Strong irritant externally and internally ; used to procure abortion
47. *Primulaceae*— (Prim-rose Family) Saponins	1. *Anagallis arvensis* Linn.	Produces gastro-enteritis in dogs and horses ; used to poison fish and expel leeches from nostrils of animals
	2. *Cyclamen persicum* Miller	Fish poison
	3. *Primula reticulata* Wall.	Stated to be poisonous to cattle
48. *Myrsinaceae*— (Ardisia Family) Saponins	1. *Maesa indica* Wall.	Leaves stated as fish poison
49. *Sapotaceae*— (Sapodilla and mohwa Family) Saponins	1. *Madhuca* (*Bassia*) *latifolia* (Roxb.) Macbride, *M. longifolia* (Linn.) Macbride	Residual cake used as fish poison ; said to be insecticide and used to kill worms on lawns (*mohwa* meal)
50. *Ebenaceae*— (Ebony Family)	1. *Diospyros ebenum* Koenig, *D. montana* Roxb., *D. paniculata* Dalz	Fish poisons

Families and active principles	Names of plants	General remarks
51. *Salvadoraceae*— (Salvadora Family)	1. *Salvadora oleoides* Dene., *S. persica* Linn.	Root bark vesicant
52. *Apocynaceae*— (Dog-bane and Oleander Family) 'dita' 'kurchi' and rauwolfia alkaloids; glucosides, e.g. cerberin, karabin, neriin, neriodorein, neriodorin, oleandrin, 1-strophanthin, thevetin etc.; bitter substances	1. *Allamanda cathartica* Linn.	Hydragogue cathartic
	2. *Cerbera manghas* Linn. (=*C. odollam* Gaertn.)	Green fruit used to poison dogs; seeds irritant poison; plant fish poison
	3. *Ervatamia dichotoma* (Roxb.) Blatter (= *Tabernaemontana dichotoma* Roxb.)	Seeds powerfully narcotic and poisonous
	4. *Holarrhena antidysentrica* Wall.	Not browsed by cattle and goats; anthelmintic; kurchicine general protoplasmic poison.
	5. *Lochnera pusilla* K. Schum (=*Vinca pusilla* Murr., *L. rosea* (Linn.), Reichb. (=*Vinca rosea* Linn.)	Cardiac poisons; *L. pusilla* regarded as poisonous to cattle
	6. *Melodinus monogynous* Roxb.	Fish poison
	7. *Nerium indicum* Mill (=*N. odorum* Soland)	Very poisonous. Used for suicidal purposes and to procure abortion; depresses nervous system and heart
	8. *Plumeria acuminata* Ait. (=*P. acutifolia* Poir.)	Milk rubefacient, used to procure abortion; internally purgative. Poisonous
	9. *Rauwolfia serpentina* Benth. ex Kurz	Hypnotic, fish poison
	10. *Thevetia peruviana* (Pers.) Merr. (=*T. neriifolia* Juss.)	All parts especially seeds very poisonous. Used to poison cattle; produces violent vomitting and purging. Action on heart like digitalis. Fish poison

53. *Asclepiadaceae*— (Milk-weed Family)	**1.** *Asclepias curassavica* Linn.	Fish poison, emetic, cathartic
	2. *Calotropis gigantea* R. Br., *C. procera* R. Br.	Milk drastic purgative, caustic ; stated to be used for suicidal and homicidal purposes and as an abortifacient and cattle poison
	3. *Cryptostegia grandiflora* R. Br.	Fatal case due to leaves reported in which persistent vomiting observed.
	4. *Cynanchum arnottianum* Wight, *C. vincetoxicum* Pers.	*C. arnottianum* used as insecticide, *C. vincetoxicum* not eaten by cattle and regarded poisonous ; root emetic.
	5. *Sarcostemona acidum* (Roxb.) Voigt (=*S. brevistigma* W. & A.)	Stated to have insecticidal properties.
	6. *Secamone emetica* R. Br.	Root acrid ; plant powerfully emetic.
	7. *Tylophora indica* (Burm. *f.*) Merr. (=*T. asthmatica* Wight and Arn.), *T. fasiculata* Buch.—Ham.	Fatal cases reported in man ; emetic ; *T. fasciculata* used as rat poison
54. *Loganiaceae*— (Nux-vomica Family) strychnine, brucine, etc.	**1.** *Strychnos colubrina* Linn., *S. nux-vomica* Linn.	Poisonous. *S. nux-vomica* seeds used as fish poison and source of strychnine, one of the deadliest poisons known, suicidal and homicidal cases recorded, employed to kill dogs ; rodents, etc.
55. *Boraginaceae*— (Borage and Sebestan Family) Alkaloids	**1.** *Heliotropium eichwaldii* Steud., *H. indicum* Linn.	Suspected to be poisonous
56. *Convolvulaceae*— (Convolvulus Family) Convolvulin, pharbitin, terpithin, terpethein, cucutalin, resin	**1.** *Calonyction muricatum* (Linn.) G. Don. (=*Ipomoea muricata* Jacq.)	See *Ipomoea*
	2. *Convolvulus arvensis* Linn., *C. scammonia* Linn.	Roots strongly purgative
	3. *Cuscuta reflexa* Roxb.	Nauseant and emetic ; used to procure abortion
	4. *Ipomoea reptans* (Linn.) Poir. (=*I. aquatica* Forsk.), *I. nil* Roth (=*I. hederacea* Jacq.), *I. purga* Heyne.	Strongly purgative ; irritant poisons in overdoses
	5. *Operculina turpethum* (Linn.) Manso (=*Ipomoea turpethum* R. Br.)	See *Ipomoea*

Families and active principles	Names of plants	General remarks
57. *Solanaceae*— (Datura and nightshade Family)	1. *Atropa belladonna* Linn.	Fatal cases of poisoning reported; dryness of mouth and throat, dilation of pupils and delirium characteristic features
	2. *Capsicum annuum* Linn., *C. frutescens* Linn., *C. minimum* Roxb.	Seeds gastro-intestinal irritant; used for torturing
	3. *Datura fastuosa* Linn., *D. metel* Linn., *D. stramonium* Linn.	Commonly used by criminals for stupefying their victims, symptoms resemble those of atropa
	4. *Hyoscyamus muticus* Linn., *H. niger* Linn., *H. pusillus* Linn., *H. reticulatus* Linn.	Cases of livestock and children poisoning on record; action like atropa
	5. *Lycium barbarum* Linn.	Reported poisonous to livestock
	6. *Mandragora caulescens* Clarke	Suspected to be poisonous
	7. *Nicandra physaloides* Gaertn.	Insecticide
	8. *Nicotiana rustica* Linn., *N. tabacum* Linn.	Insecticide, also used to ward off leeches; fatal cases reported among human beings and stock
	9. *Physochlaina praealta* Miers.	Reported poisonous
	10. *Scopolia anomala* (Link et Otto) Airy-Shaw, (*S. lurida* Dunal.)	Poisonous, action like atropa
	11. *Solanum dulcamara* Linn., *S. incanum* Linn. (=*S. coagulans* Forsk) *S. nigrum* Linn. (unripe berries), *S. spirale* Roxb., *S. tuberosum* Linn. (sprouting).	Cases of poisoning among human beings and animals reported, some fatal; gastro-intestonal irritant; occasionally associated with atropa-like symptoms
	12. *Withania somnifera* Dunal	Reported to be used as abortifacient and as an insecticide, stated to be hypnotic

58. *Scrophulariaceae*— (Mimulus and Digitalis Family) Digitalin, digitonin, digitoxin, gitalin, gitonin, etc., saponin, bitter substance	1. *Digitalis purpurea* Linn.	Cardiac poison ; fatal case due to eating of plant reported in India
	2. *Verbascum thapsus* Linn.	Fish poison, seeds narcotic
59. *Bignoniaceae*— (Bignonia Family)	1. *Dolichandrone falcata* Seem.	Fish poisons reputed to be abortifacient
60. *Pedaliaceae*— (Sesamum Family) Sesamol (a phenolic substance), seasamolin	1. *Sesamum orientale* Linn. (=*S. indicum* Linn.)	Seed cakes commonly fed to cattle in India ; stated to be toxic to livestock in Europe producing colic, tremors, dyspnoea and distention
61. *Verbenaceae*— (Verbena and teak Family)	1. *Callicarpa longifolia* Lamk. var. *lanceolaria* C. B. Clarke	Fish poison
	2. *Duranta plumieri* Jacq.	Very bitter and believed to be poisonous to livestock, but generally refused
	3. *Lantana aculeata* Linn. (=*L. camara* Linn.)	Reports about being poisonous to livestock received from the Punjab and Assam Government Departments
	4. *Stachytarpheta jamaicensis* (Linn.), Vahl, var. *indica* H. J. Lam (=*S. indica* Vahl.)	Stated to be abortifacient
	5. *Verbena officinalis* Linn.	Stated to be irritant poison
62. *Labiateae*— (Mint and sage Family) Essential oils, saponins	1. *Eremostachys acanthocalyx* Boiss, *E. vicaryi* Benth.	E. *acanthocalyx* stated to be poisonous ; E. *vicaryi* used as a fish poison
	2. *Lamium amplexicaule* Linn.	Regarded as injurious in America
	3. *Pogostemon heyneanus* Benth. (*P. patchouli* F. B. I., non Pelletier)	Leaves used against insects
63. *Chenopodiaceae*— (Spinach and beet Family) Essential oils, saponins, salsoline, oxalic acid	1. *Chenopodium ambrosioides* Linn., *C. botrys* Linn.	Anthelmintic against hook worm and round worm. Fatal poisoning on record
	2. *Haloxylon recurvum* Bunge ex Boiss., *H. salicornicum* Bunge ex Boiss.	Stated to be poisonous but *H. recurvum* is a favourite food of camels

Families and active principles	Names of plants	General remarks
63. *Chenopodiaceae*—contd.	**3.** *Salicornia brachiata* Roxb.	Ash stated to be abortifacient
	4. *Salsola kali* Linn.	Suspected poisonous but a feeding test with half dried plants in flowering stage negative
	5. *Suaeda fruticosa* Forsk.	Stated to be poisonous
64. *Phytolaccaceae*— (Phytolacca Family) Bitter substances	**1.** *Phytolacca latbenia* (Buch-Ham.) H. Walt. (=*P. acinosa* Hook. *f.*, F. B. I., non-Roxb.	Stated poisonous if eaten raw, but it is edible when cooked
65. *Polygonaceae*— (Buck-wheat and rhubarb Family) Rutin, essential oils, anthra-quinone derivatives, oxalic acid, oxalates	**1.** *Fagopyrum esculentum* Moench, *F. tataricum* Gaertn.	Commonly eaten but under certain conditions, not properly understood at present, produces eruptions and urticaria
	2. *Polygonum aviculare* Linn., *P. flaccidum* Meissn), *P. hydropiper* Linn., *P. orientale* Linn., *P. persicaria* Linn., *P. tomentosum* Willd.	*P. hydropiper* biting to a degree that no animal will eat it. Acrid, emetic, vesicant, insecticidal and piscicidal properties to varying degree strongly suspected
	3. *Rheum emodi* Wall., and probably some others	Petiole edible and so also the leaves, but latter responsible for occasional poisoning
	4. *Rumex acerosa* Linn., *R. acetosalla* Linn.	Oxalic acid poisoning if eaten in excess
66. *Aristolochiaceae*— (Birth-wort Family) Aristolochin, glucoside, essential oils, bitter substance	**1.** *Aristolochia bracteata* Retz., *A. indica* Linn.	Nauseous and bitter, emmenagogue and abortifacient ; *A. bracteata* insecticide
67. *Piperaceae*— (Pepper Family) Essential oils, piperine, piperovatine	**1.** *Piper* sp.	Harmful effects of *P. betle* Linn., *P. nigrum* Linn. well known

68. *Myristicaceae*— (Nutmeg Family) Essential oil (with myristicin), saponins	1. *Myristica fragrans* Houtt., *M. malabarica* Lamk., possibly some others also.	Narcotic ; occasional cases of poisoning reported
69. *Lauraceae*— (Laurel Family) Essential oils	1. *Cassytha filiformis* Linn. 2. *Cinnamomum camphora* F. Nees (product imported)	Stated to be used as insecticide Protective against moths ; counter-irritant, systemically stimulates then depresses and paralyses central nervous system
70. *Thymeliaceae*— (Mezereum Family) Saponins	1. *Daphne cannabina* Wall., *D. oleoides* Schreb. 2. *Edgeworthia gardneri* Meissn. 3. *Lasiosiphon eriocephalus* Dcne. 4. *Wikstroemia viridiflora* Meissn. (*W. indica* C. A. Mey, var. *viridiflora* Hook. *f.*)	Severe gastro-intestinal irritant, camels do not eat *D. oleoides* Fish poison Dust from dried plant very irritant, not eaten by livestock, fish poison Fish poison
71. *Loranthaceae*— (Mistletoe Family)	1. *Viscum* sp. and possibly others	Poisonous properties probably acquired if growing on poisonous hosts, e.g. *Strychnos nux-vomica*
72. *Euphorbiaceae*— (Croton and castor oil Family) Cyanogenetic compounds, saponins, crotonoside, ricinine, essential oils, euphorbon, phenolic substance, resins, toxalbumins	1. *Andrachne cordifolia* Muell.-Arg. 2. *Baliospermum montanum* Muell., Arg. (=*B. axillare* Blume.) 3. *Buxus sempervirens* Linn. 4. *Chrozophora rottleri* A. Juss ex Spreng. (=*C. tinctoria* Hook. *f.* in part) 5. *Cleistanthus collinus* Benth. & Hook. *f.* 6. *Croton oblongifolius* Roxb., *C. tiglium* Linn.	Cattle poisoning reported, African species used as insecticide Seeds and oil drastic purgative, seeds in overdoses acro-narcotic poison Stated to be fatal to camels and cattle ; goats probably immune Emetic and cathartic ; animals avoid it Used as fish poison and occasionally as human poison, extract violent gastro-intestinal irritant Seeds especially and the oil also drastic purgative ; poisoning reported ; seeds stated to be used as insecticide and piscicide

Families and active principles	Names of plants	General remarks
72. *Euphorbiaceae*—contd.	7. *Euphorbia acaulis* Roxb., *E. antiquorum* Linn., *E. cattimandoo* W. Elliot, *E. helioscopia* Linn., *E. hirta* Linn., *E. hypericifolia*, *E. neriifolia* Linn., *E. nivulea* Buch.-Ham., *E. peplus* Linn., *E. pilosa* Linn., *E. rothiana* Spreng., *E. royleana* Boiss., *E. thomsoniana* Boiss., *E. thymifolia* Linn., *E. tirucalli* Linn., *E. trigona* Haw	Acrid and vesicant juice in most species; some used as abortifacient when applied locally; *E. antiquorum*, *E. neriifolia*, *E. royleana*, *E. tirucalli*, fish poisons; *E. antiquorum* and *E. thymifolia* stated to be used as insecticides, some poisonous to livestock
	8. *Excoecaria agallocha* Linn.	Fresh sap extremely acrid, causes intolerable pain if it gets into eye; woodcutters have suffered, called blinding tree; fish poison
	9. *Fluggea leucopyrus* Willd., *F. virosa* Baill (=*F. microcarpa* Bl.)	Fish poison, used to destroy worms in sores
	10. *Hura crepitans* Linn.	Seeds and oil violent purgative; milky juice very irritant
	11. *Jatropha curcas* Linn., *J. glandulifera* Roxb., *J. gossypiifolia* Linn., *J. multifida* Linn.	Violent purgative like *croton* sp., *J. curcas* fish poison
	12. *Manihot utilissima* Pohl.	Fresh tubers extremely poisonous, cassava or tapioca meal specially prepared
	13. *Phyllanthus urinaria* Linn.	Stated to be fish poison
	14. *Ricinus communis* Linn.	Seeds produce violent gastro-enteritis, subcutaneously very poisonous. Oil stated to be an active poison for flies. Plant fish poison
	15. *Sapium indicun* Willd., *S. insigne* Trimen.	*S. indicun* juice narcotic poison; fruit extremely nauseous, seeds fish poison. *S. insigne* juice vesicant

73. *Urticaceae*— (Nettle, hemp and mulberry Family) α-β&γ-antiarin, saponin, resin containing cannabindol (toxic), formic acid	16. *Tragia bicolor* Miq., *T. involucrata* Linn. (with varieties)	Stinging nettles
	1. *Antiaris toxicaria* Lesch.	Sap used as an arrow poison ; powerful heart poison
	2. *Cannabis sativa* Linn.	The preparations *bhang*, *charas*, and *ganja* well known in India ; excessive indulgence, injurious physically and mentally. Plant stated to be used as a fish poison in Bengal ; spread on beds to drive away bugs
	3. *Ficus* sp.	Some species contain acrid juice ; Watt states fruits of *F. bengalensis* poisonous to horses
	4. *Fleurya interrupta* Gaud	Stings
	5. *Girardinia leschenaultiana* Dene., *G. zeylanica* Dene	Stinging nettle
	6. *Laportea crenulata* Gaud., *L. terminalis* Wight	Stinging nettle
	7. *Urtica dioica* Linn., *U. hyperborea* Jacq., *U. parviflora* Roxb., *U. pilulifera* Linn.	Stinging nettle
74. *Juglandaceae*— (Walnut Family)	1. *Juglans regia* Linn.	Rind of unripe fruit stated to be used as fish poison in Jaunsar and Tehri Garhwal
75. *Myricaceae*— (Sweet-gale Family) Essential oils, myricelin	1. *Myrica nagi* Thunb.	Bark stated to be used as fish poison in Khasia hills
76. *Gnetaceae*— (Gnetum Family) Saponins, bitter substance	1. *Gnetum scandens* Roxb.	Fish poison

Families and active principles	Names of plants	General remarks
77. *Coniferea*— (Pine Family) Essential oils, taxine, taxicatin	1. Several members, especially *Taxus baccata* Linn.	Most members possess toxic essential oil and poisoning due to the use of *Juniper oil* as abortifacient reported. Deaths in man and animals due to eating the berries and leaves of *T. baccata* reported ; seeds very poisonous ; fish poison
78. *Iridaceae*— (Iris Family) Saponins, picrocrin (bitter substance) ; essential oils	1. *Crocus sativus* Linn.	Bulbs toxic to young animals ; stigmas in overdoses narcotic poison ; used as abortifacient
79. *Amaryllidaceae*— (Amaryllis and agave Family) Saponin, Lycorine, tazettine	1. *Agave americana* Linn.	Stated as fish poison, also stated toxic to livestock under field conditions, wall paper impregnated with expressed juice said to be proof against white-ants
	2. *Crinum asiaticum* Linn., *C. latifolium* Linn.	Bulbs of *C. asiaticum* strongly emetic and nauseant, those of *C. latifolium* extremely acrid and used for blistering cattle
	3. *Narcissus tazette* Linn.	Bulbous roots emetic and purgative, irritant poison in overdoses
80. *Taccaceae*—	1. *Tacca pinnatifida* Forst.	Tuber intensely bitter, acrid and poisonous when fresh, yields nutritious starch by maceration and repeated washing
81. *Bromeliaceae*— (Pine-apple Family)	1. *Ananas sativus* Schult.	Juice of leaves and unripe fruit purgative and sometimes used as abortifacient

82. *Dioscoreaceae*— (Yam Family) Dioscorine, glucoside (toxic)	1. *Dioscorea bulbifera* Linn., *D. hispida* Dennst. (=*D. daemona* Roxb.), *D. prazeri* Prain & Burk. (=*D. deltoidea* Wall.)	Tubers are very acrid but in most cases boiling, etc. makes them edible.
83. *Liliaceae*— (Lily Family) Imperialine, colchicine, methyl-colchicine, saponine, barbaloin, emodin, sicaloin, resin, essential oils, etc.	1. *Allium sativum* Linn.	Essential oil very irritant and pungent, produces irritant poisoning in excess, also stimulant narcotic, anthelmintic
	2. *Aloe* species	Insipissated juice 'Mushabbar' of commerce powerful drastic purgative; fatal cases reported; used to procure abortion
	3. *Colchicum luteum* Baker	Resembles closely the foreign *C. autumnale* which is poisonous and produces gastro-intestinal irritation; Indian also probably poisonous
	4. *Fritillaria imperialis* Linn.	Bulbs toxic when fresh, said to be a heart poison
	5. *Gloriosa superba* Linn.	Roots stated to be sometimes used for suicidal purposes and as abortifacient, acro-narcotic poison; juice of leaves stated to be used to destroy lice in the hair
	6. *Scilla indica* Baker 7. *Urginia coromandeliana* Hook. *f.*, *U. indica* Kunth.	Bulbs irritant poison. Foreign species *U. scilla* a fish poison; Indian representatives also
84. *Juncaceae*— (Rush Family)	1. *Juncus effusus* Linn.	Suspected poisonous to livestock in South Africa. This and other species in India worth investigating
85. *Palmaceae*— (Palm Family) Arecaine, arecolidine, arecoline, guvacine, guvacoline, saponins	1. *Areca catechu* Linn.	Young and undried nut when chewed in access gives rise to temporary giddiness, also gripping and strong intestinal irritation, sometimes resulting in loose motions

Families and active principles	Names of plants	General remarks
85. *Palmaceae*—contd.	2. *Arenga obtusifolia* Mart.	Juice from fruit used by Malays to poison enemies, *A. obtusifolia* stated to be used as fish poison
	3. *Corypha umbraculifera* Linn.	Fruit stated fish poison
	4. *Wallichia disticha* T. Anders.	Watt states that berries and perhaps the leaves irritate the skin
86. *Araceae*— (Aroid Family) Calcium oxalate (acicular crystals), bitter substance, sharp acrid substance, essential oil (alkaloid and saponin in foreign plant)	1. *Acorus calamus* Linn., *A. gramineus* Soland	Roots stated to be used as effective insecticides and insectifuge. Doubtful case reported when the *A. calamus* proved poisonous to camels during the Afghan Campaign, rhizome a medicine but in overdoses produces a violent and persistent emesis
	2. *Alocasia indica* Schott, *A. montana* Schott., *A. odora* (Roxb.) C. Koch (=*A. macrorrhiza* Schott)	Fresh tubers acrid and irritant
	3. *Amorphophallus campanulatus* (Roxb.) Bl., *A. lyratus* Engl., *A. sylvaticus* (Roxb.) Kunth (*Synantherias sylvatica* Schott.)	Fresh tubers acrid and irritant ; seeds intensely acrid. Seeds of *A. sylvaticus*, like *Plesmonium*, and fruit intensely acrid
	4. *Arisaema speciosum* Mart., *A. tortuosum* Schott.	Tubers poisonous, insecticidal, fruit also probably poisonous
	5. *Homalomena rubescens* Kunth	Stated to be poisonous
	6. *Lagenandra ovata* (Linn.) Thw. (=*L. toxicaria* Dalz.)	Stated to be very poisonous ; also insecticidal
	7. *Plesmonium margaritiferum* Schott.	Crushed seeds produce local anaesthesia ; used as a cure for toothache
	8. *Sauromatum guttatum* Schott.	Tubers regarded as very poisonous

	9. *Steudnera virosa* (Kunth) Prain (= *Colocasia virosa* Kunth)	Poisonous
	10. *Thomsonia nepalensis* Wall.	Acrid when fresh
	11. *Typhonium trilobatum* (Linn.) Schott.	Fresh tubers exceedingly acrid
87. *Cyperaceae*— (Sedge Family) Essential oil	1. *Carex cernua* Boott.	Said to be one of the causes of 'vlei' poisoning in cattle in South Africa
	2. *Cyperus longus* Linn.	Regarded as poisonous in South Africa
	3. *Scirpus corymbosus* Heyne.	See *Carex cernua*
88. *Gramineae*— (Grass Family) Cyanogenetic glucosides, hydrocyanic acid, temuline, saponins, oxalic acid, selenium protein (toxic)	1. *Avena fatua* Linn., *A. sativa* Linn.	Good fodder but occasionally deleterious, probably on account of 'hair balls' that are developed in the stomach
	2. *Bambusa arundinacea* Willd.	Fresh young shoots stated to be insecticidal
	3. *Dendrocalamus strictus* (Roxb.) Nees.	Leaves stated to be used to procure abortion
	4. *Lolium perenne* Linn., *L. temulentum* Linn.	Several cases of poisoning, mostly non-fatal in man and animals, from eating the seeds of *L. temulentum*, gastro-intestinal irritation and severe nervous symptoms reported Suspected to be responsible for the production of 'Dikoor', a disease affecting young sheep in Africa Kodra poisoning very similar to *L. temulentum* poisoning, animals suffer much more than men; animals should be prevented from grazing the crop when ripening
	5. *Panicum maximum* Jacq.	
	6. *Paspalum scrobiculatum* Linn.	

Families and active principles	Names of plants	General remarks
88. *Gramineae*—contd.	7. *Sorghum halepense* (Linn.) Pers., *S. saccharatum* Pers., *S. vulgare* Pers.	Good fodder. Occasional poisoning reported, stunted growth, under drought condition ; frosted leaves, or second growth dangerous
	8. *Stipa* sp. (some)	Believed poisonous ; mechanical action of ' seeds ' may not be overlooked
	9. *Triticum aesativum* Linn.	Under certain conditions deleterious fodder
	10. *Zea Mays* Linn.	Pollen stated to be a possible cause of hay fever, said to be occasionally responsible for deleterious effects, as yet not fully understood

SAMPLING OF SUGARCANE FOR CHEMICAL ANALYSIS

BY

B. P. VAGHOLKAR, L.Ag.

Principal Agricultural Officer, Sugarcane Research Scheme for Deccan, Padegaon,

N. B. PATWARDHAN, B.Ag.

Agricultural Overseer

AND

S. SUBRAMONIA IYER, M.A.

Statistical Assistant, Imperial Council of Agricultural Research, New Delhi

(Received for publication on 14 September 1939)

(With one text-figure)

Introduction

WITH the commencement of the sugarcane research scheme for the Deccan financed by the Imperial Council of Agricultural Research, located at Padegaon, the problem of testing sugarcane varieties was the main item of work, which involved a proper sampling of cane for chemical analysis. On the Manjri Sugarcane Experimental Station, an arbitrary method of sampling for chemical analysis was adopted by taking two random clumps in the main plot (which varied from 4 to 6 *gunthas**). A good deal of difficulty is being experienced at various agricultural stations in India for lack of a proper sampling technique for chemical analysis.

A fairly complete bibliography on the work done by different workers on this subject is given in a recent publication by Narain and Singh in this Journal†. But there is necessity at all stations for undertaking research work which will lead to the best method of sampling for chemical analysis.

It may be mentioned here that at Padegaon, cane is planted in January or February, and is given 34 to 36 irrigations during the 12 months of its growth. During the maturity period from December onwards till February or March, when cane is harvested, the weather remains dry, and is unaffected by frost or rainy weather.

The following terms have been used in this paper :—

(*a*) *Clump sampling.*—This is used to denote the number of canes obtained from a three-eyebud set,

(*b*) ' *Two feet* ' *strip sampling.*—This is used to denote the number of canes obtained from a ' two-feet ' strip, which may consist of a single clump, or two or more clumps.

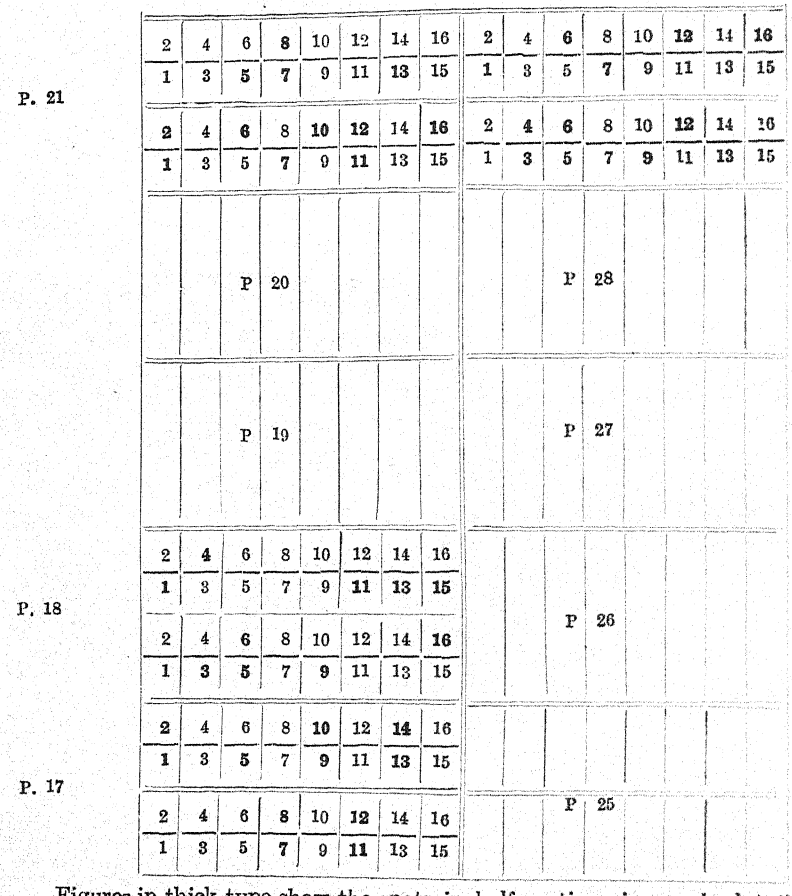
* 1 *guntha* = 1/40 acre

† Vol. 7, part IV

Material

A block of land planted with the variety Co 360 was chosen for the study of sampling for chemical analysis. The cane was planted in February 1934. The total area of the block was 128 cents*, and consisted of 32 plots, each measuring 4 cents (54·44ft. × 32ft.). From these 32 plots, four plots were chosen at random for this work, as shown in the accompanying plan.

Plan showing the location of plots in the block and random spots from where samples were collected



Figures in thick type show the spots in half-portions in a sub-plot (into which a plot is divided) from where samples have been taken.

Duration of work.—The sampling work was carried on for a period of six days — from the 7th to 12th February 1935. The first four days were devoted to clump sampling and the remaining two days for 'two-feet' strip sampling. During the course of the work, extraction tests, as also juice and cane analysis were conducted from day to day, and data with regard to these are presented in Tables I and II :—

*1 cent = 1/100 acre

TABLE I

Extraction of juice (variety Co 360)

Serial No.	Date	Weight of cane in lb.	Weight of juice in lb.	Percentage of extraction	Remarks
1	8 February 1935	2,000	1,296	64·8	
2	8 February 1935	2,000	1,305	65·2	
3	9 February 1935	2,000	1,306	65·3	Extraction tests taken on Chattanuga No. 45 power mill
4	9 February 1935	2,000	1,304	65·2	
5	11 February 1935	1,843	1,198	65·0	
6	11 February 1935	758	490	64·6	
7	12 February 1935	1,129	763	67·6	
8	12 February 1935	1,413	953	67·4	

TABLE II

Analysis of juice and cane (of Table I)

Serial No.	Date	Juice analysis				Cane analysis	
		Brix	Sucrose	Glucose	Purity	Sucrose per cent	Fibre per cent
1	8 February 1935	19·66	173·5	0·50	89·17	14·58	12·90
2	8 February 1935	21·16	19·63	0·33	92·79	16·45	11·42
3	9 February 1935	21·19	20·45	0·18	93·35	16·93	13·81
4	9 February 1935	21·67	20·05	0·28	92·53	17·41	10·50
5	11 February 1935	22·97	21·33	0·32	92·87	18·18	10·80
6	11 February 1935	19·82	17·92	0·68	90·38	16·07	11·98
7	12 February 1935	21·43	19·58	0·49	91·37	16·69	12·61
8	12 February 1935	22·17	20·34	0·34	91·77	17·58	11·01

The power-driven mill used in these tests was Chattanuga No. 45. Similarly, for obtaining juice for analysis of clumps and ' two-feet ' strips, the same mill was used.

Statistical examination of the data

Thick figures in the plan indicate the locations or squares from which clumps were taken ; each square was 11¼ ft. in length, and squares were taken at random to make up in all 45 clumps from each plot. The number of squares so taken varied from nine to twelve in the four plots taken.

Two-feet strip samples were similarly taken from the squares adjoining the ones from which clumps were taken. The number of two-feet strips taken from each square was four to make up 36 strips per plot.

The data thus consist of 45 clump samples from each of four plots and 36 two-feet strip samples also from each of the same four plots, providing comparison between the two methods of sampling.

For clump sampling, number of canes per clump, average weight per cane, brix and sucrose percentages are calculated and given in the appendix. For two-feet strip samples, similar data were calculated except sucrose percentages.

Number of canes per clump varied between two and eight in two plots, between two and ten in the third plot and between two and nine in the fourth plot. The analyses of variance of the number of canes per clump and average weight per cane are given in Table III.

Table III (*a*)

Number of canes per clump

Due to	Degrees of freedom	Sum of squares	Mean square
Between plots	3	20·33	6·7778
Between clumps and within plots	176	512·22	2·9103
Total (between clumps)	179	532·55	..

Average weight per cane per clump

Between plots	3	10·7464	3·5821
Between clumps and within plots	176	109·4061	0·6216
Total (between clumps)	179	120·1525	..

TABLE III (*b*)

Two-feet strip sampling

Number of canes per strip

Due to	Degrees of freedom	Sum of squares	Mean square
Between plots	3	26·7986	8·9329
Betweenstrips and within plots	140	489·0278	3·4930
Total (between strips)	143	515·8264	..

Average weight per cane

Between plots	3	14·0538	4·6846
Between strips and within plots	140	74·3362	0·5310
Total (between strips)	143	88·3900	..

The coefficient of variation for number of canes per clump is 36·80 per cent and number of canes per two-feet strip is 36·54 per cent. Hence there is a high variation in the number of canes per sample which is about the same in both the methods. For the average weight of cane the two methods gave coefficients of variation of 24·22 per cent and 21·98 per cent which were also high.

To study whether there is any correlation between the number of canes per clump or per two-feet strip and average weight per cane the analysis of covariance was worked out and the results are given below :—

TABLE IV (*a*)

Analysis of covariance (clump sampling)

Due to	Degrees of freedom	Sum of products	Mean sum of products
Plots	3	2·8562	0·9521
Within plots	176	−52·4427	−0·2980
Total	179	−49·5865	..

TABLE IV (*b*)

Analysis of covariance (*strip sampling*)

Due to	Degrees of freedom	Sum of products	Mean sum of products
Plots	3	−5·3856	−1·7952
Within plots	140	−60·7861	−0·4342
Total	143	−66·1717	..

The correlation coefficient after elimination of plot-variance works out to be −0·2215 ($P<0·05$) in clump sampling and −0·3188 ($P<0·05$) in strip sampling. This shows that there is a significant negative correlation, though not very high, between the number of canes per clump and average weight per cane.

Relation between weight and sucrose percentage (*clump sampling*)

Fig. 1 shows the relationship between total weight of cane and sucrose percentage. There seems to be no correlation between these two factors and this agrees with the conclusions obtained by Davies [1930] working at Trinidad.

The analysis of variance for the data of sucrose percentage (in clump sampling) is as below :—

TABLE V

Analysis of variance (*sucrose percentage in clump sampling*)

Due to	Degrees of freedom	Sum of squares	Mean square
Between plots	3	121·8810	40·6270
Within plots	176	124·8804	0·7095
Total	179	246·7614	..

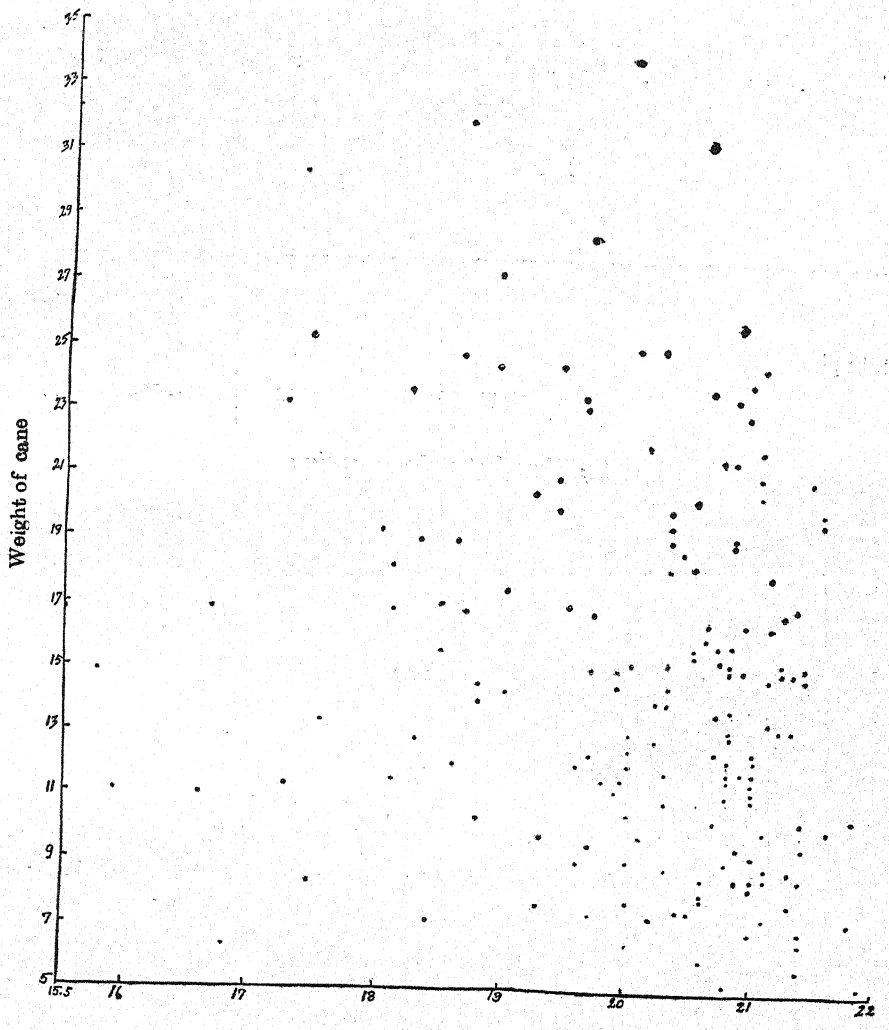


FIG. 1. Weight of cane and sucrose percentage of each of the clumps

The coefficient of variation is 4·17 per cent, which shows that the variation from sample to sample is very small.

Brix sampling

The brix figures are available for both the methods of sampling studied in this paper, and analyses of variance for ' brix ' are given below :—

TABLE VI

(*a*) *Clump sampling*

Due to	Degrees of freedom	Sum of squares	Mean square
Between plots	3	82·7135	27·5712
Within plots	176	121·7569	0·6918
Total	179	204·4704	..

(*b*) *Two-feet strip sampling*

Between plots	3	36·5198	12·1733
Within plots	140	99·8934	0·7135
Total	143	136·4132	..

The arithmetic mean, standard deviation and coefficient of variation are shown below :—

(*a*) *Clump sampling*		(*b*) *Two-feet strip sampling*	
Mean	22·02	Mean	22·26
Standard deviation	0·83	Standard deviation	0·84
Coefficient of variation	3·76	Coefficient of variation	3·77

The standard error of the mean of 45 units for clump sampling is 0·123 and this gives an idea of the extent to which the mean is likely to vary from the mean of the entire field. The plot brix mean percentages per clump for the four plots are 22·52, 22·17, 20·87, 22·51. In the case of two-feet strip sampling the standard error of the mean of 36 units is 0·140 and the plot means are 22·71, 21·53, 22·05, 22·74. These show that we may consider that the samples by either method are fairly representative of the field.

Size of the sample for any standard of accuracy

From a knowledge of the extent of variation from sample to sample it is possible to calculate the number of clumps or the number of strips as the case may be which should be taken from a plot in order to measure a difference of say 5 per cent in brix readings and for any standard of accuracy, say at $P=0·05$ or $P=0·01$. This may be calculated easily or read directly from published tables [Vaidyanathan, 1936]. Using these tables for $P=0·05$, we get the number of clumps or the number of two-feet strips to be five for the plots considered, i.e. of area 0·04 acre (the coefficients of variation being about 3·8 per cent in either case).

Similarly for the sucrose percentage which gives a coefficient of variation of 4·17 per cent, the number of samples (clumps) required to measure a 5 per cent difference in sucrose percentage at $P=0\cdot05$ also comes to five.

Summary

Two methods of sampling for chemical analysis have been tried, one on the basis of 45 clumps per plot and the other on the basis of 36 two-feet strips (taken at random). The number of samples required by either method to measure differences of the order of 5 per cent for $P=0\cdot05$ in brix or sucrose percentage have been found to be five.

The extent of variation and correlation between average weight of cane and number of canes per sampling unit by both the methods, and also the correlation between weight of cane and sucrose percentage in the case of clump sampling have been examined.

Acknowledgement

The scheme is financed by the Imperial Council of Agricultural Research to whom the authors' thanks are due. The authors wish to thank, in particular, Rao Bahadur M. Vaidyanathan, Statistician, Imperial Council of Agricultural Research, for his valuable help and guidance.

References

Ramji Narain and Azmat Singh (1937). *Ind. J. Agric. Sci.* **7**, 601—26

Davies, J. G. (1930). *Mem. Imp. Coll. Trop. Agric. (Trinidad) Sugar Technology Series No.* **3**

Vaidyanathan, M. (1936). *Imp. Coun. Agric. Res. Misc. Bull. No.* **13**

Appendix I

CLUMP SAMPLING

P. No. 29

Sample No.	No. of canes per clump	Average weight per cane	Brix	Sucrose in juice
1	4	3·62	21·94	20·27
2	3	4·33	21·38	19·99
3	7	3·57	21·82	20·16
4	2	5·25	21·64	20·00
5	5	3·00	22·79	20·90
6	5	4·00	20·90	19·40
7	4	3·69	22·87	21·12
8	3	3·25	21·53	20·05
9	3	3·08	22·77	20·96
10	5	3·35	20·77	18·66
11	5	2·65	23·15	21·25
12	4	2·37	23·29	21·40
13	4	2·58	23·35	21·42
14	5	3·35	23·12	21·20
15	5	3·05	22·80	21·17
16	3	3·42	22·50	20·74
17	3	3·83	21·60	19·79
18	4	2·50	23·04	21·14
19	4	3·25	22·54	20·79
20	5	4·20	23·04	21·38
21	6	3·91	22·62	20·84
22	3	2·50	22·23	20·46
23	5	2·10	23·54	21·79
24	3	2·92	23·10	21·33
25	2	3·87	23·22	21·31
26	4	2·81	22·94	21·01
27	6	3·00	22·99	21·12
28	7	3·11	22·74	21·01
29	4	2·19	22·03	20·27
30	3	3·37	23·37	21·64
31	4	2·12	22·70	20·92
32	3	2·58	21·15	19·25
33	6	3·29	23·10	21·49
34	6	1·87	21·55	19·90
35	8	2·50	23·27	21·50
36	7	2·55	22·50	20·76
37	4	4·24	22·97	21·25
38	6	3·16	22·53	20·79
39	6	3·18	22·59	20·79
40	6	2·54	21·98	20·27
41	6	2·46	23·00	21·38
42	4	4·00	22·43	20·61
43	6	1·98	22·67	20·92
44	5	3·00	22·57	20·84
45	5	2·50	22·90	21·04

P. No. 18

Sample No.	No. of canes per clump	Average weight per cane	Brix	Sucrose in juice
1	5	2·32	22·43	19·85
2	5	4·00	22·43	20·34
3	5	3·00	21·78	19·87
4	6	4·75	21·40	19·59
5	7	4·50	22·35	20·46
6	7	3·35	21·29	19·56
7	5	4·10	22·63	20·95
8	4	3·31	22·96	21·21
9	6	3·96	22·30	20·61
10	3	4·58	22·76	20·74
11	2	2·62	22·58	20·84
12	7	3·50	20·69	18·92
13	5	4·95	20·60	18·65
14	5	3·65	22·63	20·45
15	3	4·66	22·09	20·27
16	2	2·50	23·09	21·24
17	3	2·58	21·76	19·98
18	3	3·00	21·89	19·60
19	4	3·62	21·96	19·94
20	8	2·75	21·96	20·07
21	2	4·25	23·26	21·17
22	3	2·42	21·89	20·20
23	4	4·56	22·30	20·34
24	3	4·16	22·63	20·74
25	4	3·12	22·76	20·98
26	8	2·44	21·91	20·30
27	5	2·55	22·13	20·17
28	2	3·25	21·47	19·77
29	5	4·90	20·75	19·42
30	7	4·86	21·67	19·79
31	5	3·00	22·40	21·33
32	6	2·54	21·69	19·82
33	4	2·87	22·98	21·04
34	8	2·87	22·75	20·90
35	3	4·08	23·07	20·82
36	7	3·43	22·80	20·90
37	3	3·92	22·32	20·84
38	5	5·45	20·73	18·93
39	4	4·19	21·60	19·74
40	3	3·75	20·90	18·85
41	4	3·94	22·59	20·73
42	4	3·06	22·73	20·96
43	2	3·00	22·70	20·64
44	4	3·31	23·00	21·16
45	3	5·00	22·90	21·20

P. No. 17

Sample No.	No. of canes per clump	Average weight per cane	Brix	Sucrose in juice
1	8	2·89	21·58	19·59
2	3	2·66	22·53	20·61
3	3	3·16	21·70	19·72
4	5	4·00	22·13	20·30
5	5	3·10	20·38	18·50
6	4	4·25	20·73	18·53
7	5	2·30	20·33	18·10
8	7	2·93	20·16	18·05
9	8	2·12	18·20	15·53
10	7	4·57	20·65	18·58
11	3	4·00	21·62	19·56
12	5	4·30	22·60	20·79
13	5	3·00	21·43	19·67
14	4	3·62	22·10	20·27
15	6	2·00	20·83	18·61
16	4	2·44	21·56	19·32
17	5	2·30	19·76	17·29
18	6	2·83	19·10	16·69
19	4	3·50	20·89	18·81
20	8	3·19	19·94	17·51
21	4	3·19	20·62	18·28
22	3	3·92	22·06	20·25
23	4	2·25	22·09	19·85
24	4	2·81	18·68	16·55
25	6	3·04	20·32	18·11
26	5	2·25	18·61	15·87
27	5	3·50	20·91	18·96
28	8	2·94	19·66	17·32
29	6	3·16	20·96	18·28
30	8	2·62	21·59	19·42
31	4	4·25	21·57	19·53
32	4	3·12	21·73	19·93
33	7	2·75	20·15	17·98
34	6	2·50	18·30	15·76
35	3	4·50	19·62	17·64
36	3	5·50	22·77	20·92
37	5	3·80	22·20	20·27
38	4	3·50	22·39	20·23
39	3	5·25	22·70	20·84
40	4	3·62	20·85	18·76
41	10	2·37	20·59	18·18
42	7	2·71	20·58	18·61
43	2	2·25	20·96	19·12
44	8	2·56	21·00	19·23
45	3	2·83	20·06	17·47

P. No. 21

Sample No.	No. of canes per clump	Average weight per cane	Brix	Sucrose in juice
1	2	2·87	23·06	21·40
2	4	3·34	22·70	21·12
3	2	2·62	23·64	21·91
4	5	3·30	22·60	20·58
5	4	2·25	22·56	20·82
6	4	2·06	23·10	21·04
7	9	2·78	21·91	19·91
8	3	3·87	22·38	20·76
9	2	2·44	22·96	21·06
10	2	3·63	22·34	21·09
11	4	2·50	22·56	20.79
12	6	3·12	22·34	20·39
13	6	1·58	22·87	20·93
14	7	2·91	22·53	20·53
15	5	2·40	21·36	19·74
16	3	2·92	22·24	21·06
17	3	2·83	22·97	20·96
18	3	2·25	22·81	20·96
19	4	3·81	22·89	21·37
20	7	3·68	22·66	20·79
21	4	1·78	20·49	18·44
22	5	2·17	22·12	20·03
23	3	2·50	22·89	20·45
24	3	3·96	22·70	21·01
25	3	2·29	23·07	21·39
26	7	3·50	22·69	20·95
27	6	3·60	22·66	20·74
28	3	4·37	22·52	20·82
29	3	2·83	22·96	21·35
30	4	3·94	22·56	20·53
31	4	1·97	22·71	20·61
32	2	3·62	23·04	21·75
33	3	2·54	22·76	20·93
34	7	1·75	21·32	19·74
35	3	2·42	21·68	19·69
36	4	3·84	22·43	20·66
37	5	2·85	20·76	18·93
38	7	2·21	22·10	20·54
39	8	2·64	22·69	21·01
40	3	2·83	22·31	20·56
41	3	5·08	22·93	20·82
42	4	2·78	22·79	20·84
43	2	3·25	23·31	21·44
44	3	3·66	22·56	21·01
45	5	3·27	22·56	21·06

Appendix II

TWO-FEET STRIP SAMPLING

P. No. 29

Sample No.	No. of canes per strip	Average weight per cane	Brix
1	3	4·75	22·13
2	5	3·20	22·63
3	8	3·67	22·70
4	3	4·66	21·91
5	5	4·30	23·18
6	7	2·82	23·36
7	4	1·44	21·69
8	4	2·75	23·18
9	2	3·00	22·85
10	5	2·42	23·18
11	6	2·46	22·40
12	7	3·78	23·23
13	5	3·90	23·73
14	2	3·75	22·83
15	5	3·35	23·10
16	6	2·29	23·09
17	4	3·75	22·86
18	4	4·53	21·23
19	7	3·34	21·21
20	3	3·33	23·36
21	4	2·22	22·87
22	5	2·20	22·70
23	3	3·00	23·21
24	8	1·86	22·97
25	2	3·62	22·80
26	9	3·11	21·70
27	5	3·00	22·33
28	5	2·50	22·86
29	5	2·47	22·77
30	4	2·75	22·23
31	5	2·27	23·21
32	7	2·18	22·93
33	7	1·78	22·53
34	4	2·56	23·19
35	5	3·30	22·16
36	4	3·28	23·28

P. No. 17

Sample No.	No. of canes per strip	Average weight per cane	Brix
1	7	3·39	20·27
2	6	5·16	22·76
3	5	2·42	22·23
4	4	3·78	22·37
5	6	4·33	21·47
6	6	3·75	22·03
7	8	3·19	22·33
8	6	2·81	22·61
9	6	2·96	21·82
10	7	2·61	22·63
11	5	3·05	22·69
12	4	2·47	21·90
13	4	2·68	20·94
14	2	5·00	21·23
15	8	2·53	20·16
16	8	2·28	22·10
17	4	3·37	20·11
18	7	3·11	21·93
19	5	3·00	23·29
20	5	2·58	21·77
21	5	3·55	21·00
22	7	2·21	19·66
23	12	2·85	19·96
24	8	2·94	24·03
25	4	3·75	21·77
26	3	3·37	22·98
27	8	3·62	23·13
28	5	3·25	22·17
29	6	3·77	20·91
30	7	4·30	21·00
31	4	3·25	21·26
32	8	2·45	19·13
33	6	2·50	19·76
34	7	3·07	19·82
35	5	1·95	20·55
36	2	4·12	21·22

P. No. 18

Sample No.	No. of canes per strip	Average weight per cane	Brix
1	4	3·50	21·63
2	4	3·50	23·27
3	6	3·17	22·60
4	2	5·50	22·33
5	4	4·00	20·66
6	5	3·60	22·00
7	6	4·92	22·27
8	6	4·00	21·83
9	4	4·25	20·92
10	7	3·14	22·00
11	9	2·44	21·90
12	5	4·00	22·23
13	3	4·33	22·49
14	3	3·00	22·69
15	3	4·17	21·00
16	4	2·62	21·06
17	5	5·50	22·59
18	7	3·43	22·23
19	6	4·25	22·53
20	4	3·75	21·60
21	5	4·60	22·96
22	3	4·33	23·17
23	3	4·67	22·26
24	5	3·40	19·20
25	7	3·37	22·76
26	2	3·50	22·59
27	6	3·58	22·66
28	4	4·50	19·66
29	4	3·50	21·93
30	2	4·50	22·43
31	5	2·80	22·93
32	9	3·67	22·86
33	6	4·00	22·86
34	3	3·50	23·04
35	4	3·62	22·39
36	8	4·06	20·42

P. No. 21

Sample No.	No. of canes per strip	Average weight per cane	Brix
1	5	3·80	22·90
2	4	3·12	22·99
3	8	2·94	22·97
4	4	2·38	23·43
5	8	2·44	22·70
6	3	3·50	22·80
7	4	3·62	22·80
8	4	3·62	23·29
9	8	3·44	23·43
10	6	2·42	22·63
11	4	3·37	23·06
12	9	3·33	22·60
13	5	3·50	22·13
14	3	2·83	23·11
15	4	2·25	22·88
16	6	2·83	22·01
17	5	2·20	22·83
18	3	3·67	21·76
19	3	4·67	22·67
20	2	3·50	22·93
21	3	3·00	21·69
22	4	3·25	23·06
23	4	3·00	23·10
24	3	3·66	23·29
25	4	3·75	22·35
26	6	3·42	22·73
27	3	3·67	23·24
28	4	3·00	22·43
29	9	2·67	22·46
30	4	4·00	22·84
31	4	1·88	21·96
32	3	4·33	22·26
33	4	3·50	22·99
34	7	3·29	23·10
35	8	2·19	22·66
36	5	2·60	22·63

STUDIES ON INDIAN RED SOILS

I. BUFFER CURVES AND BASE-EXCHANGE REACTIONS

BY

S. P. RAYCHAUDHURI

AND

A. B. NANDY MAZUMDAR

Agricultural Chemistry Section, Dacca University

(Received for publication on 3 July, 1939)

(With nine text-figures)

Introduction

As yet there is no satisfactory method of classifying the red soils which occur in different parts of India. They are often designated as laterites or lateritic, irrespective of their physico-chemical properties. The present paper aims at classifying some of the typical red soils in India from studies of base-exchange properties of the soils including the study of buffer curves and of total exchangeable bases and the percentage base saturation. The changes in the water-holding capacities and percentages of imbibitional water of the soils after saturation with lime at *p*H 7·1 have also been studied.

Experiments and results

A. Buffer curves

(*a*) *Determination of buffer curves.*—The determination of lime-requirements of soils at different *p*H values and the examination of the buffer curves were carried out by following essentially the method devised by Schofield [1933]. The principles of this method are : (*a*) that the solution of an acid has maximum buffer action at its half neutralized stage, and (*b*) that if a soil be shaken with a mixture of lime and an organic acid whose calcium salt is soluble, the soil will take up base from the solution or give up base to the solution depending on the relative differences in the *p*H values between the soil and the solution. Hence by shaking a weighed quantity of a soil with a mixture of lime and the organic acid, we can bring the acid to the half-neutralized stage. If the amount of base-uptake be plotted as abscissa and the corresponding *p*H values as the ordinate, the characteristic buffer curve of a soil would be that which passes through the plotted points on the curve.

The organic acids which were used in these determinations and their *p*H values at half neutralized points are as follows :—

Name of acids	*Formula*	p*H at half neutralized point*
Monochlor acetic . . .	$CH_2Cl.COOH$ . .	2·9
Acetic	CH_3COOH . . .	4·6
p-nitrophenol . . .	$C_6H_4(NO_2)OH$ . .	7·1
Phenol.	C_6H_5OH . . .	9·8

The uptake of bases at *p*H 1·3 and 12·5 were determined by treating the soils with 0·05 *N* hydrochloric acid and 0·04 *N* barium hydroxide respectively

(*b*) *Determination of* p*H.*—The *p*H values were obtained at soil : water ratio of 1 : 2·5 by Kuhn's barium sulphate method and a Hellige colorimeter.

(*c*) *Determination of percentage carbonate contents.*—The carbonate contents of soils were determined by Collin's calcimeter.

(*d*) *Determination of saturation capacity at* p*H 7·0.*—The saturation capacities at *p*H 7·0 were determined by the barium-acetate-ammonium-chloride method of Parker [1929].

(*e*) *Determination of total exchangeable bases.*—The total exchangeable bases of the soils were determined by the method of William [1929]. The observed figures of exchangeable bases were corrected for the carbonate contents of the soils, wherever the soil contained measurable amounts of carbonate. Since the carbonate contents of the soils were never very large, such a correction was thought to be justifiable. A blank determination using no soil was made in order to correct for the exchangeable bases in the reagents and in the filter paper employed.

(*f*) *Determination of exchangeable calcium.*—The method of determining exchangeable calcium was essentially that used by Williams [1929]. The observed figures of exchangeable calcium were corrected for the carbonate figures. Here again since the percentage of carbonate in the soils was in all cases quite low, such a correction was thought to be justifiable.

Results and discussions

A. Buffer curves

The data on the uptake of base at different *p*H values are shown in Table I.

Table I

Milli equivalent base taken up by 100 gm. of over-dry soil

Lab. No.	*p*H 1·3	*p*H 2·9	*p*H 4·6	*p*H 7·1	*p*H 9·8	*p*H 12·5	Fig. No.
1p	—4·0	—1·8	1·2	5·6	15·4	21·5	1
2p	—4·2	—2·0	3·7	8·6	21·3	29·7	
3p	—7·9	—2·9	3·2	7·4	21·0	30·6	
4p	—1·7	—0·6	0·9	2·7	7·6	10·9	2
5p	—5·8	—1·9	0·7	3·4	11·0	16·4	
6p	—11·1	—5·4	—1·3	3·3	15·2	25·0	
7p	—17·6	—13·2	—9·1	—2·1	5·6	13·8	
8p	—5·5	—2·5	—0·9	0·9	4·0	7·3	
10p	—34·2	—15·9	—3·9	4·4	19·7	31·3	3
11p	—18·6	—10·8	—3·1	2·6	18·1	31·7	
12p	—12·8	—8·0	—2·9	1·6	13·6	24·9	
14p	—6·1	—3·0	—0·7	3·1	15·1	22·3	
18p	—9·6	—4·3	—2·5	1·3	6·7	12·7	4
19p	—23·4	—6·6	—1·5	2·6	13·7	24·7	
20p	—30·9	—5·9	—1·7	1·3	4·4	15·1	

TABLE I—*contd.*

Lab. No.	*p*H 1·3	*p*H 2·9	*p*H 4·6	*p*H 7·1	*p*H 9·8	*p*H 12·5	Fig. No.
23p	—36·4	—16·8	—5·5	5·4	35·8	58·5	
24p	—38·9	—17·6	—5·3	7·0	39·8	78·9	
25p	—59·3	—17·6	—6·0	1·4	28·8	36·9	
26p	—85·0	—21·8	—4·8	1·5	27·2	60·2	
27p	—76·6	—12·4	—3·5	2·1	20·9	40·0	
33p	—6·0	—2·6	—0·9	3·8	14·0	22·5	5
34p	—10·1	—4·4	—1·4	6·5	20·3	29·8	
35p	—13·7	—5·6	—2·8	3·9	17·1	27·5	
42p	—10·3	—5·9	—2·5	1·7	7·8	13·2	
43p	—16·0	—6·2	—2·6	2·1	13·5	22·8	
45p	—10·3	—3·3	—2·1	4·2	17·6	24·8	
46p	—13·8	—4·8	—4·6	2·7	16·3	24·5	
48p	—1·9	—0·6	0·0	1·3	4·5	6·8	
49p	—5·6	—1·7	—0·6	1·3	8·1	9·4	
50p	—7·7	—1·1	—0·4	0·7	6·1	13·0	
51p	—11·8	—2·3	—0·9	0·0	5·7	16·8	
53p	—26·8	—15·4	—7·2	0·4	13·2	27·4	6
54p	—18·1	—5·8	—1·8	1·7	13·5	25·0	
55p	—28·9	—5·5	—1·5	1·3	14·0	25·9	
56p	—10·0	—5·9	—1·8	10·2	33·1	41·1	7
57p	—7·5	—3·0	—0·5	10·2	32·5	41·2	
58p	—8·5	—4·9	—1·9	6·0	25·2	37·1	
59p	—7·1	—2·8	1·9	16·4	59·8	..	
60p	—7·7	—4·9	—3·3	6·0	27·4	36·5	8
61p	—11·5	—7·3	—4·6	5·6	28·4	39·2	
62p	—12·1	—6·4	—2·5	6·9	25·5	38·1	
63p	—12·2	—5·5	—2·2	3·8	19·6	32·3	
64p	—8·6	—3·9	—1·8	1·3	10·8	18·0	
65p	—23·0	—14·3	—7·8	—1·3	4·6	19·3	
67p	—33·2	—18·0	—13·4	—2·3	6·5	19·3	
68p	—41·5	—17·2	—7·9	—0·5	11·7	31·9	
70p	—4·8	—1·8	0·3	4·5	16·1	23·2	
71p	—5·3	—1·6	0·5	5·0	16·8	19·9	
73p	—8·7	—4·4	—2·8	1·7	12·3	19·9	
74p	—7·3	—2·2	—1·1	1·3	12·3	20·3	

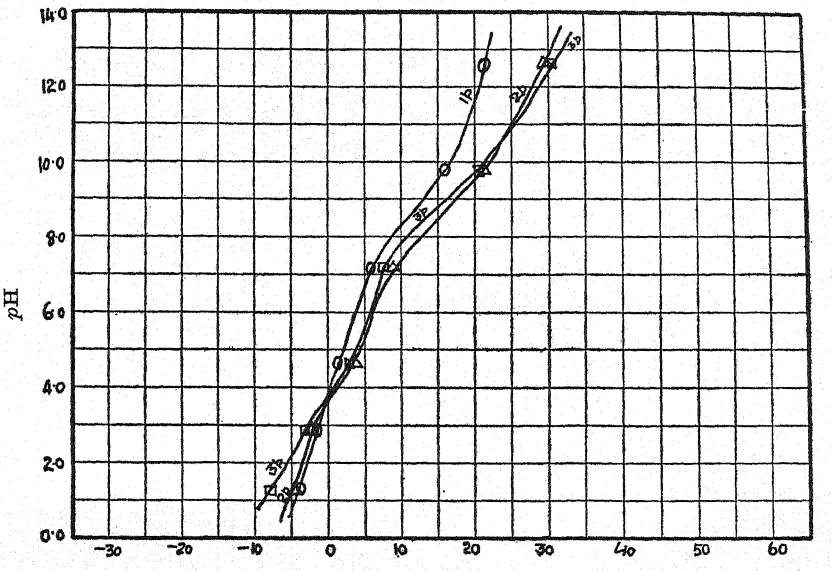


FIG. 1. Milli equivalent base taken up by 100 gm. oven-dry soil (Dacca, Bengal)

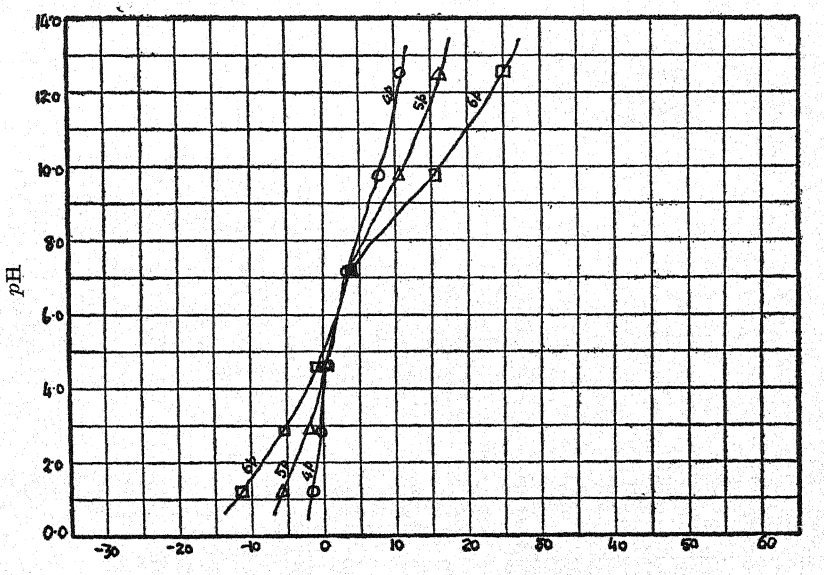


FIG. 2. Milli equivalent base taken up by 100 gm. oven-dry soil (Suri, Bengal)

As typical examples of the nature of the buffer curves, those of the samples from Dacca (Bengal), Suri (Bengal), Bidar (Hyderabad), Himayatsagar (Hyderabad), Raipur (C. P.), and Nilgiri Hills (Madras), are shown in Figs. 1-5. It will be noticed that almost all the curves indicate a more or less definite

inflexion at pH 9·8 and a second inflexion either at pH 2·9 or at pH 4·6. It was felt desirable to determine the buffer values ($\beta = \frac{\Delta B}{\Delta p\text{H}}$) at pH's 2·9, 4·6 and 9·8 from the buffer curves. Table II shows the calculated buffer values.

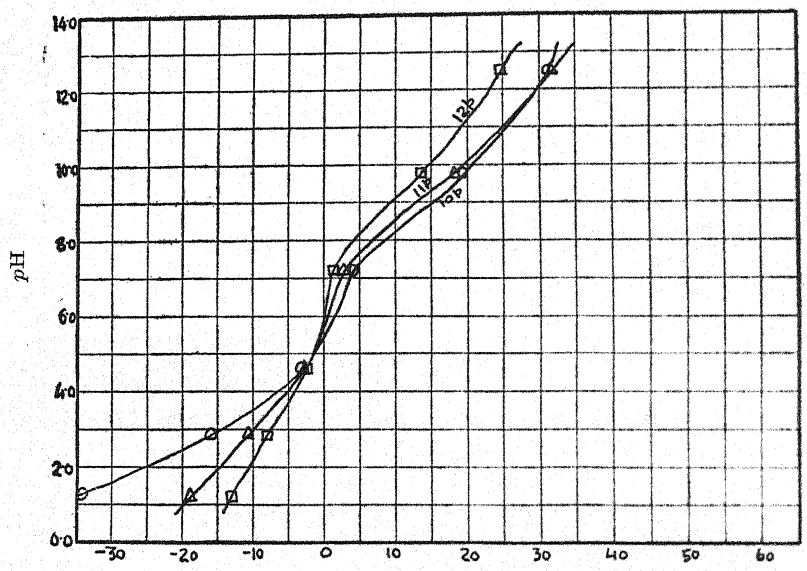


FIG. 3. Milli equivalent base taken up by 100 gm. oven-dry soil (Bidar, Hyderabad)

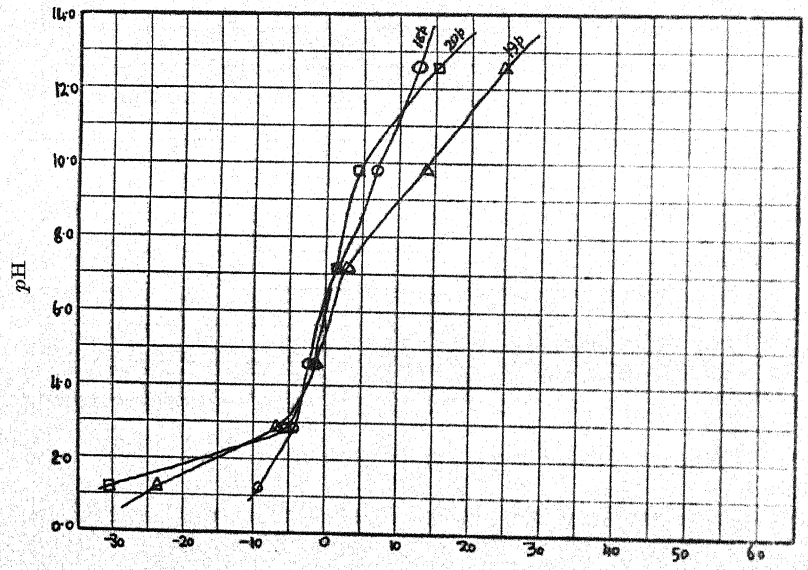


FIG. 4. Milli equivalent base taken up by 100 gm. oven-dry soil (Himayatsagar, Hyderabad)

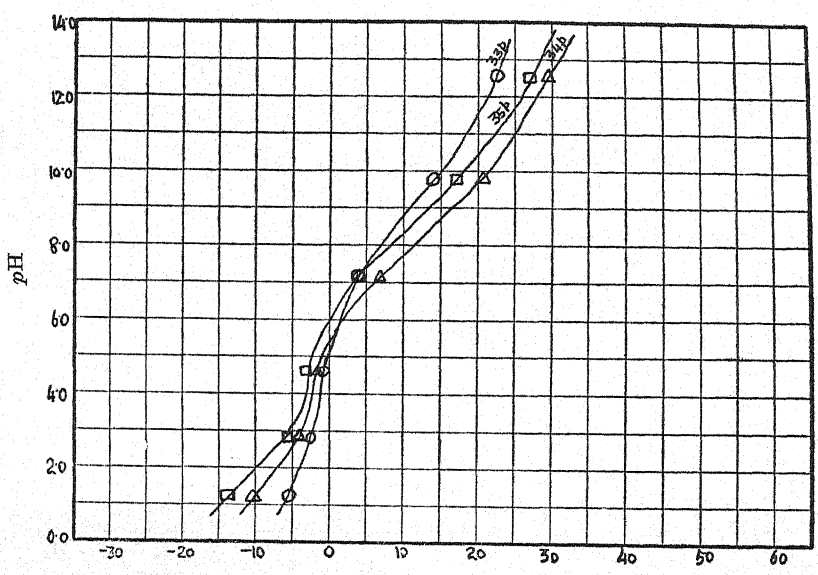


FIG. 5. Milli equivalent base taken up by 100 gm. oven-dry soil (Raipur, C. P.)

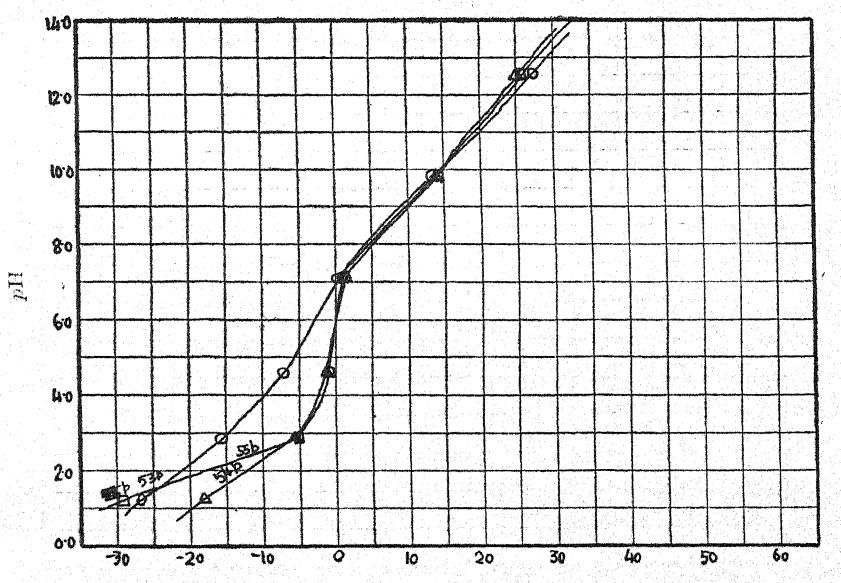


FIG. 6. Milli equivalent base taken up by 100 gm. oven-dry soil (Nilgiri Hills, Madras, 3,000 ft. above sea-level)

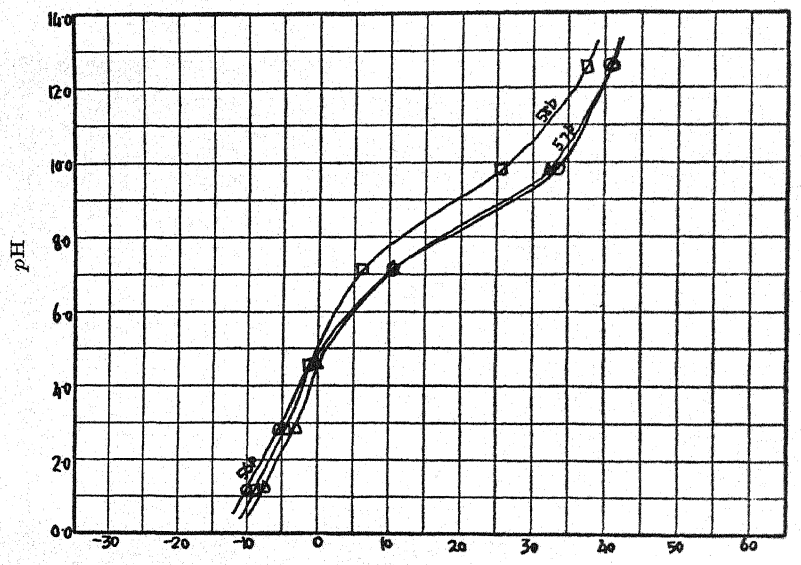


FIG. 7. Milli equivalent base taken up by 100 gm. oven-dry soil (Nilgiri Hills, Madras, 5,000 ft. above sea-level)

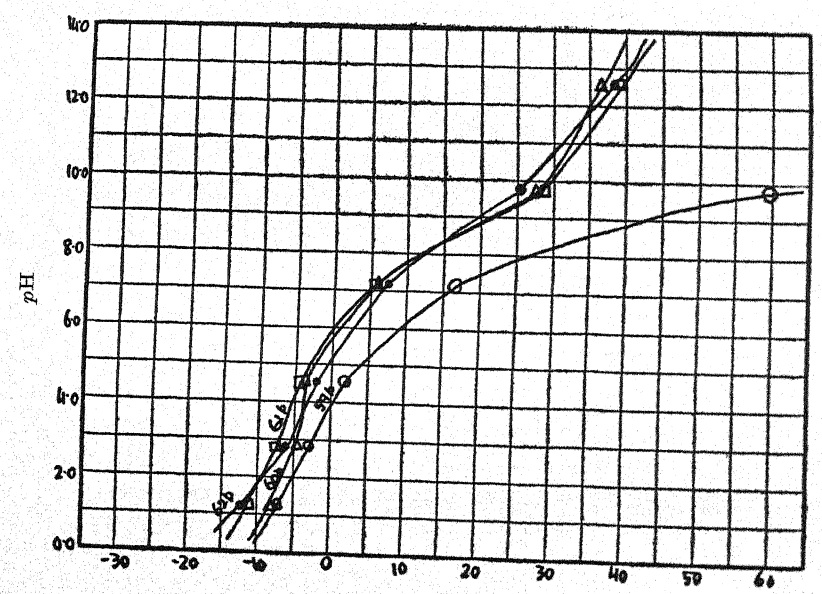


FIG. 8. Milli equivalent base taken up by 100 gm. oven-dry soil (Nilgiri Hills, Madras, 7,000 ft. above sea-level)

TABLE II

Locality	Lab. No.	Depth	*p*H 2·9	*p*H 4·6	*p*H 9·8
Dacca Farm, Bengal .	1p	0 in.—6 in.	0·0015	0·0018	0·0038
	2p	6 in.—2 ft. 3 in.	0·0018	0·0032	0·0041
	3p	2 ft. 3 in.—4 ft.	0·0033	0·0030	0·0053
Suri, Birbhum, Bengal .	4p	0 in.—1 ft.	0·0010	0·0010	0·0020
	5p	1 ft.—1 ft. 6 in.	0·0020	0·0015	0·0030
	6p	1 ft. 6 in.—4 ft.	0·0034	0·0021	0·0052
Bidar, Hyderabad . .	10p	0 in.—1 ft.	0·0087	0·0047	0·0063
	11p	1 ft.—3 ft.	0·0047	0·0035	0·0063
	12p	3 ft.—4 ft.	0·0033	0·0025	0·0060
Himayatsagar, Hyderabad .	18p	0 in.—3 in.	0·0023	0·0007	0·0017
	19p	3 in.—1 ft. 6 in.	0·0067	0·0010	0·0043
	20p	1 ft. 6 in.—4 ft.	0·0070	0·0007	0·0027
Raipur, Central Provinces .	33p	0 in.— 4 in.	0·0015	0·0005	0·0040
	34p	4 in.—1 ft. 5 in.	0·0030	0·0010	0·0048
	35p	1 ft. 5 in.—4 ft.	0·0030	0·0010	0·0053
Nilgiri Hills (3,000 ft. above sea-levels) (1)	53p	0 in.—1 ft. 8 in.	0·0060	0·0040	0·0046
	54p	1 ft. 8 in.—3 ft.	0·0047	0·0017	0·0043
	55p	below 54p	0·0042	0·0013	0·0048
Nilgiri Hills (5,000 ft. above sea-levels) (2)	56p	0 in.—1 ft.	0·0023	0·0026	0·0038
	57p	1 ft.—2 ft.	0·0020	0·0015	0·0040
	58p	2 ft. 6 in.—6 ft.	0·0020	0·0017	0·0043
Nilgiri Hills (7,000 ft. above sea-levels) (3)	59p	0 in—1 ft.	0·0028	0·0027	..
	60p	1 ft.—3 ft.	0·0030	0·0022	0·0047
	61p	3 ft.—4 ft. 6 in.	0·0021	0·0015	0·0040
	62p	4 ft. 6 in.—6 ft.	0·0013	0·0010	0·0037

No regular variation of $\frac{\Delta B}{\Delta pH}$ down the soil profiles is observed. In some cases the manner of variation of $\frac{\Delta B}{\Delta pH}$ at the three *p*H values is not the same.

Within certain limits of variation, however (approximately 10 per cent), it is possible to classify the soil profiles into four divisions :

1. Increase* of $\frac{\Delta B}{\Delta pH}$ down the profile : Dacca, Suri and Raipur.
2. Decrease* of $\frac{\Delta B}{\Delta pH}$ down the profile : Bidar (Hyderabad), Nilgiri Hills (1) and Nilgiri Hills (3).

*An average of the variation of $\frac{\Delta B}{\Delta pH}$ at the three *p*H values, 2·9, 4·6 and 9·8, is noted.

3. Maximum value* of $\frac{\Delta B}{\Delta p H}$ at an intermediate depth : Himayatsagar (Hyderabad).

4. Value of $\frac{\Delta B}{\Delta p H}$ is fairly constant* down the profile : Nilgiri Hills (2).

Mention may be made here of the work of Anderson and Byers [1936] who have found that the character of neutralization curves made with sodium hydroxide varies widely for colloids of different soil groups. The colloids of Pedocal soils show the strongest acid character. The colloids of the lateritic soils have much weaker acid qualities than those of the Pedocal soils, and their titration curves are of such markedly different form that the two groups are readily differentiated by this means. The Prairie group and the Gray-Brown Podzolic group have titration curves intermediate in character between those of the Pedocal and the lateritic soils. The Pedocal soil colloids require about 0·55 milli equivalent per gm. to reach the neutral point (pH 7), those from the Prairie soils just a little less, approximately 0·5, and the Gray-Brown Podzolic group covers the range from nearly 0·5 to about 0·2, which is near the maximum quantity required by the lateritic colloid.

Puri and Asghar [1938] have performed electrometric titrations of soils after removing from them exchangeable bases by leaching the soils with 0·05 N hydrochloric acid and using glass electrode for measuring the pH values.

In our present investigations we have used natural soils with no pretreatment, since Schofield's procedure of obtaining buffer curves is obviously suitable for working directly with natural soils.

In a series of publications on the potentiometric and conductometric titrations of silicic acid sols, humic acid sols and acid clays, Mukherjee, and coworkers have been investigating as to whether the classical treatment of electrochemical equilibria is sufficient for an adequate representation of the properties of these substances (for a review of this series of publications, see Mukherjee, Mittra and Mukherjee [1937]) . They have shown that electrometric titration curves usually afford valuable information regarding the total acidities, dissociation constants, and basicity of acids or mixtures of acids in true solutions. But when the solid phase is present, the interpretation is not as simple. Mention may also be made of the work of Bradfield [1924] who has shown that the manner of variation of pH of electrodialysed clay with its concentration is of the same nature as that of a weak acid, like acetic acid, and has thus concluded that the colloidal fraction of an acid soil can itself be considered to be an acid which ionizes to produce a definite Sorensen value and show a definite titratable acidity or normality on titration with strong bases. Puri and Asghar [1938] have also concluded from their results that the titration curves of soil acidoids closely resemble those of weak dibasic acids. It may also be interesting to note that Puri has defined the terms exchangeable bases, exchangeable hydrogen, base-exchange capacity and saturation capacity in

*An average of the variation of $\frac{\Delta B}{\Delta p H}$ at the three pH values, 2·9, 4·6 and 9·8, is noted.

terms of the acidoid equivalent of the soil samples, thus giving an interpretation to these terms which bears no reference to any particular method of estimating these quantities.

Attempt at a discussion of the nature of buffer curves on the same lines as the electrometric titration curves would be, at this stage of our knowledge, quite premature. The study of the buffer curves has, however, an interesting feature. Different soils have different but specific constituents with specific buffer capacities. It is suggestive, therefore, that for characterizing the soil types from the point of view of soil survey, the study of buffer curves might be of interest and of significant importance.

It is difficult to suggest the significance of the inflexions of the buffer curves at *p*H's 2·9, 4·6 and 9·8 and the problem is under investigation. Mention may be made here of the potentiometric titrations of sodium silicate solutions with hydrochloric acid carried out by Joseph and Oakley [1925], Harman [1927], Britton [1927] and with sulphuric acid by Krestinskaja and Moltschanowa [1936]. The results of these investigations show an inflexion near about *p*H 11·0, which indicates a definite stage of neutralization at this *p*H. This inflexion has been supposed by Harman to correspond to the formation of acid silicate ($NaHSiO_3$).

Krestinskaja and Moltschanowa, on the other hand, conclude that the inflexion at *p*H 11·0 represents the neutralization of hydroxyl ions produced by the hydrolysis of sodium silicate :

$$SiO_3'' + H_2O \leftrightarrows HSiO_3' + OH'$$

Harman and Britton have observed a second inflexion between *p*H's 5 and 6. They regard this second inflexion to represent the complete liberation of silicic acid whilst Krestinskaja and Moltschanowa consider the second inflexion to represent the neutralization of the hydroxyl ions derived from the hydrolysis of the acid silicate :

$$HSiO_3' + H_2O \leftrightarrows H_2SiO_3 + OH'$$

Krestinskaja and Moltschanowa also observed a third inflexion at *p*H 4·5, which they suggest might be due to the decomposition of a complex silicate stable in the acid region.

Since in the composition of soils silicates predominate, it is quite possible that the inflexion points in the buffer curves of soils might be analogous to those observed in the case of potentiometric titration curves of sodium silicate solutions. The free alumina present in the soil samples probably also play an important role in determining the nature of the buffer curves.

B. Experiments with electrodialysed soils

The soil samples 53p—55p from the Nilgiri Hills were electrodialysed * and the buffer curves of the soils are shown in Fig. 9.

Regarding the nature of the buffer curves of the electrodialysed soils it is found that up to about *p*H 7·1, all the curves are almost linear. The curves

*The process of electrodialysis was carried out in a 3-chambered electrodialysis vessel of Pauli's pattern. The soil was kept in the middle chamber and electrodialysis was carried out until the liquid at the cathode was neutral.

for the electrodialysed soils 53p and 55p show an inflexion at pH 9·8, whilst that for 54p does not. This behaviour of the soils is indeed very striking in comparison with the behaviour of the same soils, unelectrodialysed, which show an exactly opposite behaviour.

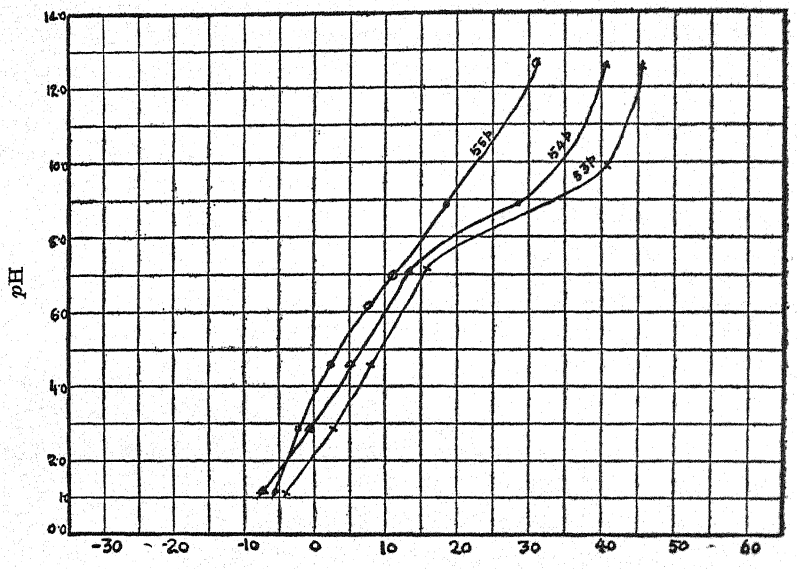


FIG. 9. Milli equivalent base taken up by 100 gm. oven-dry electrodialysed soil (Nilgiri Hills, 3,000 ft. above sea-level)

C. Base-exchange reactions

Table III gives in one place the pH values, the milli equivalent exchangeable bases per 100 gm. oven-dry soil (x), the saturation capacities in milli equivalent base per 100 gm. oven-dry soil (y), percentage base saturation $(\frac{x}{y} \times 100)$, milli equivalent exchangeable calcium per 100 gm. oven-dry soil (z), exchangeable calcium as percentage of total exchangeable bases $(\frac{z}{x} \times 100)$ and finally exchangeable calcium as percentage of total saturation capacity $(\frac{z}{y} \times 100)$.

It will be noticed that in general the percentage base saturation decreases down the following profiles: Dacca and Nilgiri Hills (2). In the case of the profile from Bidar, the percentage base saturation increases with increase in the depth. In the case of the profiles from Suri and Nilgiri Hills (3), the percentage base saturation shows a maximum value at intermediate layers. The Himayatsagar, Raipur and Nilgiri Hills (1) profiles, on the other hand, show a minimum percentage base saturation at intermediate layer.

TABLE III

Locality	Lab. No.	Depth	pH	x	y	$\frac{x}{y}\times 100$	z	$\frac{z}{x}\times 100$	$\frac{z}{y}\times 100$
Dacca Farm, Bengal .	1p	0 in.—6 in.	5·2	2·61	5·6	46·60	1·43	54·96	25·54
	2p	6 in.—2 ft. 3-in.	5·3	3·63	8·35	43·38	1·22	33·70	14·61
	3p	2 ft. 3 in.—4 ft.	5·2	4·69	11·4	41·14	1·63	34·77	14·30
Suri, Birbhum, Bengal	4p	0 in.—1 ft.	5·4	1·39	2·4	56·00	0·67	48·37	27·9
	5p	1 ft.—1 ft. 6 in.	5·4	3·48	5·50	63·27	2·52	64·71	45·8
	6p	1 ft. 6 in.—4 ft.	6·2	7·63	13·90	54·85	4·97	65·22	35·8
Bidar, Hyderabad .	10p	0 in.—1 ft.	6·2	8·38	11·00	76·20	21·10	252·00 (?)	191·9 (?)
	11p	1 ft.—3 ft.	6·2	12·12	14·30	84·75	11·39	93·99	79·7
	12p	3 ft.—4 ft.	6·4	9·5	10·40	91·30	9·02	94·99	86·7
Himayatsagar, Hyderabad.	18p	0 in.—3 in.	6·4	5·46	6·00	91·00	4·38	80·23	74·7
	19p	3 in.—1 ft. 4 in.	6·4	10·04	15·69	64·35	7·46	74·35	47·8
	20p	1 ft. 4 in.—4 ft.	7·3	10·96	13·90	78·82	7·94	72·44	57·1
Raipur, Central Provinces.	33p	0 in.—4 in.	5·8	3·83	4·40	87·07	2·13	55·46	48·4
	34p	4 in.—1 ft. 5 in.	5·8	6·83	9·30	73·33	4·36	63·89	46·9
	35p	1 ft. 5 in.—4 ft.	6·4	7·48	9·30	78·00	3·60	48·09	37·5
Nilgiri Hills (3,000 ft. above sea-level) (1).	53p	0 in.—1 ft. 8 -in.	6·8	18·92	19·58	96·62	14·91	78·8	76·1
	54p	1 ft. 8 in.—3 ft.	6·4	7·98	13·04	61·19	5·18	70·4	44·5
	55p	Below 54p	6·4	8·72	14·03	62·13	5·90	67·6	42·0
Nilgiri Hills (5,000 ft. above sea level) (2).	56p	0 in.—1 ft.	5·5	5·66	10·64	53·15	2·86	50·6	26·9
	57p	1 ft.—2 ft.	5·4	1·94	9·49	20·41	0·28	17·8	3·9
	58p	2 ft. 6 in.—6 ft.	5·4	1·72	13·90	12·37	...	...	...
Nilgiri Hills (7,000 ft. above sea-level) (3).	59p	0 in.—1 ft.	5·2	5·03	12·64	39·79	2·44	48·60	19·3
	60p	1 ft.—3 ft.	5·2	2·73	3·21	85·04	0·31	11·32	9·7
	61p	3 ft.—4 ft. 6 in.	5·6	1·61	3·31	48·64	0·39	24·20	11·8
	62p	4ft. 6 in.— 6 ft.	5·7	2·58	5·21	49·52	0·34	13·20	6·5

The ratio of exchangeable calcium to the total exchangeable bases expressed as percentage ($\frac{z}{x}\times$ 100), in general, decreases down the profile. The figures are often quite low, showing that in such cases exchangeable bases other than calcium predominate, e.g. Dacca, Suri and Nilgiri Hills (2 and 3). The sample 10p seems to be extraordinarily rich in calcium*, perhaps it contains gypsum.

*Duplicate determinations of exchangeable calcium were, however, fairly concordant.

The values of $\frac{z}{y}$ are important in this sense that they give an idea of the comparative lime-status of the soil. The following profiles show a decrease of $\frac{z}{y}$ values down the profile : Dacca, Raipur, Nilgiri Hills (1 and 2).

The profile from Suri shows a maximum value at intermediate depth, whilst profiles from Bidar and Himayatsagar show a minimum value of $\frac{z}{y}$ at an intermediate depth. From the point of view of soil genetics it would appear that the profiles which show an increasing lime-status at greater depths have been produced under comparatively more waterlogged or less free drainage conditions. In agreement with this postulation it will be noticed that the prevailing lime-status of the three profiles from the Nilgiri Hills which were taken at altitudes 3,000 ft. (1), 5,000 ft. (2) and 7,000 ft. (3) are approximately in the order (1) > (2) > (3).

Mattson and Wiklander [1937] have defined two amphoteric points of a soil colloid thus :

(*a*) The equi-ionic point of a soil is defined as that *p*H of a solution which is unaffected by the addition of the soil in its completely unsaturated, free-acid-base ampholytoid condition. In other words, it is that *p*H of the soil at which the absolute capacities to bind acid (y) and base (x) are equal, i.e. at which the net capacity to bind acid or base is equal to zero, i.e. $x-y=0$.

(*b*) The point of exchange neutrality is defined as that *p*H of a soil suspension which is unaffected by the addition of a neutral salt. It is that *p*H at which the increments produced by the salt in the capacities of the soil to combine with the anions and cations of the solution are equal, or where $(x_1-x)-(y_1-y) = 0$, where x and y represent the capacities to bind base and acid respectively in water and x_1 and y_1 the corresponding capacities in a salt solution.

In the application of the ideas of Mattson in the present instance there is one point to be considered. Although the adsorbable cation is the same throughout, namely calcium, the adsorbable anions vary. Assuming that the adsorbability of the anions is the same, it follows that the point of intersection of the buffer curves of electrodialysed soils with the line of zero adsorption should correspond to the equi-ionic point of the soil. Also from general considerations it is evident that the *p*H at which the buffer curves intersect the line of zero uptake of base should be, from theoretical considerations, the same as the *p*H of the soil. Table IV records the *p*H of the samples as obtained by Kuhn's barium sulphate method and the *p*H at which the buffer curves intersect the line of zero uptake of base.

It will be noticed from the table that generally the *p*H indicated by the intersection of the buffer curve with the line of zero adsorption is lower than that obtained by Kuhn's method. This is probably due to the exchange acidity developed by the contact of the soil with the electrolytes present in the buffer solution. In several instances, however, the agreement between the *p*H values obtained by the two methods is quite satisfactory (cp. 7p, 11p, 12p, 18p, 26p, 27p, 33p, 34p, 42p, 46p, 49p, 51p, 53p, 54p, 55p, 56p, 58p, 63p, 68p, 73p, 74p). In a few cases the *p*H obtained from the intersection of the buffer

curve with the line of zero adsorption is higher than that obtained from Kuhn's method, e.g. 45p, 61p, 62p, 64p and 67p.

TABLE IV

Lab. No.	*p*H by Kuhn's method	*p*H from the intersection of the buffer curves with the line of zero adsorption	Lab. No.	*p*H by Kuhn's method.	*p*H from the intersection of the buffer curves with the line of zero adsorption
1p	5·2	3·9	45p	5·8	6·2
2p	5·3	3·6	46p	6·3	6·6
3p	5·2	3·7	47p	6·1	..
4p	5·4	3·6	48p	5·3	4·6
5p	5·4	4·1	49p	5·4	5·6
6p	6·2	5·2	50p	6·4	5·6
7p	7·8	8·0	51p	7·2	7·1
8p	6·6	5·5	53p	6·8	6·9
10p	6·2	5·7	54p	6·4	6·2
11p	6·2	5·9	55p	6·4	6·2
12p	6·4	6·2	56p	5·5	5·2
14p	6·4	..	57p	5·4	4·8
18p	6·4	6·5	58p	5·4	5·7
19p	6·4	6·0	59p	5·2	3·9
20p	7·3	6·5	60p	5·2	5·6
23p	6·3	5·9	61p	5·6	6·4
24p	6·4	5·7	62p	5·7	6·2
25p	7·1	5·6	63p	5·8	5·9
26p	6·7	6·5	64p	5·9	6·4
27p	6·8	6·5	65p	6·4	..
33p	5·8	5·7	67p	6·4	7·8
34p	5·8	5·5	68p	7·5	7·3
35p	6·4	6·0	70p	5·6	4·4
42p	6·2	6·5	71p	5·7	4·3
43p	7·2	6·2	73p	6·3	6·6
			74p	6·2	6·5

D. Influence of saturation with lime at p*H 7·1 on the maximum water-holding capacities and of percentages of imbibitional water*

Most plants have their optimum *p*H of growth at about neutral point. It was felt desirable to examine as to how far saturation of soil with lime at *p*H 7·1 affects the maximum moisture-holding capacities and the percentages of imbibitional water of some Indian red soils as determined by Keen-Rackzkowski box experiment.

E. Saturation of soils with lime at p*H 7·1*

In obtaining the soils saturated with calcium at *p*H 7·1 the buffer method of Schofield [1933] has been used. About 100 gm. of soil were treated in a

wide-mouthed bottle with about 250 c.c. of 0·06 *N* p-nitrophenol solution half-neutralized with lime. The mixture was allowed to settle overnight, and on the following day a measured amount of the clear supernatant liquid was pipetted off and titrated with 0·05 *N* hydrochloric acid. The bulk of the supernatant liquid was then decanted off, fresh stock of buffer solution was added to the soil and the whole process was repeated until there was no change in the titration figure of the supernatant liquid. The soil was filtered off in a Buchner funnel, dried in air, passed through 1-mm. sieve and finally stocked in a wide-mouthed bottle.

F. Keen-Rackzkowski box experiment

The boxes used for the experiments were 5 cm. in internal diameter and 1·5 cm. in internal height. The determinations were made as described by Coutts [1932]. Following the work of Fisher [1924], the measurements with the Keen box were made with xylene as well. Fisher assumed that unlike water, xylene is not imbibed by the colloidal material of the soil. The imbibitional moisture capacity, according to Fisher, thus represents the volume of water retained by unit volume of soil, less the volume of xylene retained by the same soil. In the determination of xylene equivalent, the procedure followed by Russell and Gupta [1934] was used.* The boxes were overfilled with air-dry soil. They were then put at 110°C. in an electric oven for 18 hours, allowed to cool in a desiccator, gently repacked and the surplus soil scraped off with a knife. The boxes were weighed and put in xylene to a depth just covering the bottom of the box, in a circular glass trough as in the case of water. The soil was kept in contact with xylene for a period of 18 hours and the final weights of the boxes were noted.

Table VII shows that in general the maximum water-holding capacities and the maximum xylol-holding capacities of these red soils increase on saturating the soil with lime. It may be stated here that, in agreement with the observations given in the following tables, Singh and Nijawan [1936] have shown that the rate of percolation and water-holding capacity of soils containing increasing amounts of exchangeable calcium is invariably followed by an increase in the rate of percolation and water-holding capacity of the soil.

The observations made in field experiments that treatment with lime generally increases the productivity of the land, considered in conjunction with our laboratory data, thus suggest that in cases where the maximum water-holding capacity is increased on saturating the soil with lime, the application of lime in the land should show a response in the increased yield of crops. In the cases where it decreases on saturation with lime, the application of lime by farmers should not show appreciable response in the yield of crops. Pot experiments to test this hypothesis are in contemplation. It is not possible to say anything about the change suffered by the percentages of imbibed water on saturation with lime. In the case of a considerable number of soils the percentage of imbibed water decreases, whilst, in the case of an almost equal number of soils, it increases on saturation with lime.

*The wettings were done in air since it was observed that within the limits of experimental error there was very little difference between the maximum amounts of a liquid held by a soil when wetted in vacuum and in air.

TABLE V

Original soil

(Results expressed on oven-dry basis)

Locality	Lab. No.	Maximum water-holding capacity	Maximum xylol-holding capacity*	Vol. of imbibed water per 100 gm. soil
Dacca Farm, Bengal . .	1p	47·9	40·3	2·7
	2p	50·9	39·1	6·5
	3p	50·0	38·8	6·5
Suri, Birbhum, Bengal . .	4p	27·7	14·2	11·8
	5p	38·3	31·4	3·0
	7p	47·6	40·1	2·6
	8p	36·4	30·3	2·4
Bidar, Hyderabad . .	10p	42·5	37·2	0·7
	11p	50·3	43·0	2·1
Himayatsagar, Hyderabad .	18p	33·3	28·3	1·6
	19p	50·5	36·3	9·3
	20p	39·9	29·1	7·2
Telankeri, Nagpur (C. P.) .	23p	52·4	34·1	14·2
	24p	67·3	42·1	20·0
Telankeri, Nagpur (C. P.) .	26p	73·4	44·6	23·3
	27p	53·1	35·8	12·9
Raipur (C. P.) . . .	33p*	37·2	27·9	5·9
Alisagar, Hyderabad . .	42p**	31·3	22·7	5·8
Kokat, Cannanore, Malabar .	45p**	45·3	32·9	8·3
Nilgiri Hills, Madras (3,000 ft.)	53p	48·7	34·8	9·6
	54p	52·1	33·9	14·0
	55p	42·4	33·5	4·8

*Xylol used (E. Merck) was dehydrated with anhydrous calcium chloride.

**Experiments could not be carried out on profile basis as some soil samples were exhausted.

TABLE VI

Soil saturated with lime at pH 7·1

(Results expressed on oven-dry basis)

Locality	Lab. No.	Maximum water-holding capacity	Maximum xylol-holding capacity *	Vol. of imbibed water per 100 gm. soil
Dacca Farm, Bengal	1p	49·7	36·7	8·5
	2p	52·2	40·5	6·7
	3p	50·4	38·3	7·3
Suri, Birbhum, Bengal	4p	30·8	23·9	3·9
	5p	39·8	28·9	7·3
	7p	57·2	..	..
	8p	37·8	33·0	0·8
Bidar, Hyderabad	10p	45·8	39·9	1·0
	11p	56·5	44·2	6·9
Himayatsagar, Hyderabad	18p	36·8	24·4	9·4
	19p	49·2	35·0	10·0
	20p	44·3	29·3	11·4
Telankeri, Nagpur (C. P.)	23p	62·5	40·3	17·3
	24p	67·3	42·2	20·0
Telankeri, Nagpur (C. P.)	26p	70·0	54·0	9·4
	27p	51·3	42·0	4·2
Raipur, Central Provinces	33p**	37·5	..	..
Alisagar, Hyderabad	42p**	32·8	26·1	3·5
Kakat, Cannanore, Malabar	45p**	41·4	34·8	2·4
Nilgiri Hills, Madras (3,000 ft.)	53p	49·8	33·8	11·9
	54p	49·5	39·5	5·2
	55p	47·2	36·7	6·0

*Xylol used (E. Merck) was dehydrated with anhydrous calcium chloride.

**Experiments could not be carried out on profile basis as some soil samples were exhausted.

TABLE VII

Differences of the data in Tables V and VI

(Saturated soil—original soil)

Locality	Lab. No.	Maximum water-holding capacity	Maximum xylol-holding capacity	Vol. of imbibed water per 100 gm. soil
Dacca Farm, Bengal . .	1p	1·8	—3·6	5·8
	2p	1·3	1·4	0·2
	3p	0·4	—0·5	0·8
Suri, Birbhum, Bengal .	4p	3·1	9·7	—7·9
	5p	1·5	—2·5	4·3
	7p	9·6	9·9	—2·6
	8p	1·4	—4·2	—1·6
Bidar, Hyderabad . .	10p	3·3	2·7	0·3
	11p	6·2	1·2	4·8
Himayatsagar, Hyderabad .	18p	3·5	—3·9	7·8
	19p	1·3	1·8	0·7
	20p	4·4	0·2	4·2
Telankeri, Nagpur (C. P.) .	23p	10·1	6·2	3·1
	24p	0·0	0·1	0·0
Telankeri, Nagpur (C. P.) .	26p	—3·4	9·4	—13·9
	27p	—1·8	6·2	—8·7
Raipur, Central Provinces .	33p	0·3	5·1	..
Alisagar, Hyderabad . .	42p	1·5	3·4	—2·3
Kakat, Cannanore, Malabar	45p	—3·9	1·8	—5·9
	53p	1·1	—1·0	2·3
Nilgiri Hills, Malabar (3,000 ft.)	54p	2·6	—0·1	—8·8
	55p	4·8	4·2	1·2

SUMMARY

1. Buffer curves were obtained in the case of a number of soils representing several typical red soil profiles from Dacca (Bengal), Suri (Bengal), Bidar (Hyderabad), Himayatsagar (Hyderabad), Chandkhuri Farm (Raipur, C. P.), Nilgiri Hills (Madras, 3,000 ft. 5,000 ft., and 7,000 ft. above sea-level). Data for some typical base-exchange properties were also obtained, e.g. maximum saturation capacity, percentage base saturation and percentage of exchangeable calcium.

2. Almost all the buffer curves indicate a more or less definite inflexion at *p*H 9·8 and frequently a second inflexion either at *p*H 2·9 or at *p*H 4·6. The buffer values $\frac{\Delta B}{\Delta pH}$ of the soils at *p*H's 2·9, 4·6 and 9·8 were calculated from the curves and within certain limits of variations (approximately 10 per cent) it is possible to classify the profiles into the following four groups :

(*a*) Increase of $\frac{\Delta B}{\Delta pH}$ down the profile : Dacca, Suri and Raipur.

(*b*) Decrease of $\frac{\Delta B}{\Delta pH}$ down the profile : Bidar, Nilgiri Hills (3,000 ft. and 7,000 ft. above sea-level).

(*c*) Maximum value of $\frac{\Delta B}{\Delta pH}$ at intermediate layer : Himayatsagar.

(*d*) $\frac{\Delta B}{\Delta pH}$ fairly constant down the profile : Nilgiri Hills (5,000 ft. above sea-level).

3. The percentage base-saturation, in general, decreases down the following profiles : Dacca and Nilgiri Hills (5,000 ft. above sea-level). It shows a tendency to increase with the profile from Bidar. In the case of the profile from Suri and Nilgiri Hills (7,000 ft. above sea-level) the percentage base-saturation shows a maximum value at intermediate layers. The Himayatsagar, Raipur and Nilgiri Hills (3,000 ft. above sea-level) profiles on the other hand show a minimum percentage base-saturation at an intermediate layer.

4. In general the ratio of exchangeable calcium as percentage of total exchangeable bases decreases down the profile. These ratios are often quite low, showing that in such cases exchangeable bases other than calcium predominate.

5. The ratio of exchangeable calcium to the total saturation capacity shows a decrease down the following profiles : Dacca, Raipur, Nilgiri Hills (3,000 ft. and 5,000 ft. above sea-level). The profiles from Suri show a maximum value at intermediate depth, whilst profiles from Bidar and Himayatsagar show a minimum value of the ratio at intermediate depth of the profile.

6. A number of red soils of India collected on profile basis were treated with half-neutralized p-nitrophenol calcium buffer of *p*H 7·1 until the soils were saturated with lime. The soils were subsequently freed from adhering salts. The following properties of these soils before and after treatment with lime-buffer were compared :

(*a*) Maximum water-holding capacity.

(*b*) Maximum xylene-holding capacity.

(*c*) Percentage imbibitional water.

It is found that in general the maximum water-holding and the maximum xylene-holding capacities increase on saturation with lime. The percentage of imbibitional moisture-holding capacity, however, does not show such general behaviour.

ACKNOWLEDGEMENTS

Thanks of the authors are due to the Imperial Council of Agricultural Research, with the help of whose grant the soil samples were collected. The authors are also thankful to Prof. J. C. Ghosh for his kind interest in the work.

REFERENCES

Anderson, M. S. and Byers, H. G. (1936). *U. S. Dept. Agric. Tech. Bull. No.* **542,** 1-38

Bradfield, R. (1924). *J. Phys. Chem.* **28,** 170

Britton, H. T. S. (1927). *J. Chem. Soc.* **129,** 425-36

Coutts, J. R. (1932). *J. Agric. Sci.* **22,** 203

Fisher, E. A. (1924). *J. Agric. Sci.* **14,** 204-20

Harman, A. W. (1927). *J. Phys. Chem.* **31,** 616-25

Joseph, A. F. and Oakley, H. B. (1925). *J. Chem. Soc.* **127,** 2813-8

Krestinskaja, W. N. and Moltschanowa, O. S. (1936). *Kolloid Z.* **76,** 60-72

Mattson, S. and Wiklander, L. (1937). *Ann. Agric. Coll. Seweden* **4,** 169-89

Mukherjee, J. N., Mittra, R. and Mukherjee S. (1937). *Trans. Nat. Inst. Sci. Ind.* **1,** 227-92

Parker, F. W. (1929). *J. Amer. Soc. Agron.* **21,** 1030-9

Puri, A. N. and Asghar, A. G. (1938). *Soil Sci.* **45,** 359-67

Russell, E. W. and Gupta, R. S. (1934). *J. Agric. Sci.* **24,** 315-25

Schofield, R. K. (1933). *J. Agric. Sci.* **23,** 252-4

Singh, D. and Nijawan, S. D. (1936). *Ind. J. Agric. Sci.* **6,** 956-72

Williams, R. (1929). *J. Agric. Sci.* **19,** 589-99

FORMATION OF OIL IN SOME OLEIFEROUS *BRASSICAE*

BY

ALI MOHAMMAD, M.Sc. (AGRI.), L.AG.

Botanist for Oilseeds, Punjab Agricultural College and Research Institute, Lyallpur

AND

SULTAN AHMAD, B.SC. (AGRI.)

Chemical Assistant, Oilseeds Section, Lyallpur

(Received for publication on 1 July 1938)

OF the oilseed crops commonly grown in Northern India, *toria* (*Brassica napus* L. var. *dichotoma* Prain) and *sarson* (*Brassica campestris* L. var. *sarson* Prain) occupy an important position as regards acreage in the Punjab. A review of the literature available on these two crops shows that practically no work has so far been done on the course of formation of oil in the developing seeds in order to ascertain the period of most rapid oil formation and thus to coordinate the results obtained from such a study with the effect of various factors governing the yield and quality of the oil. In order to obtain some evidence on this point, the Oilseed Section, Lyallpur, has during the past three years made a few preliminary investigations which form the subject matter of this note. A brief reference to the results obtained in 1936-37 was made in the progress report, submitted to the Imperial Council of Agricultural Research, on the scheme for additional research on oilseeds in the Punjab for that year. The observations were then made on the crops grown with two irrigations and without the application of any manure. The experiments were repeated on both *toria* and brown *sarson* during the two subsequent seasons (1937-38 and 1938-39), and in order to widen the scope of these investigations the following manurial and irrigation treatments were included in the trials :—

(*i*) No manure and no irrigation

(*ii*) No manure but one irrigation applied at the commencement of critical stage of oil formation (*vide* results obtained in the year 1936-37)

(*iii*) No manure and two irrigations, i.e. one at the commencement of critical stage of oil formation and second during the maximum fruiting period

(*iv*) Farmyard manure equivalent to 25 lb. of nitrogen per acre applied before sowing and two irrigations as above

(*v*) *Toria* cake equivalent to 25 lb. of nitrogen per acre applied before sowing and two irrigations as above

(*vi*) Sodium nitrate equivalent to 25 lb. of nitrogen per acre applied at the commencement of critical stage of oil formation and two irrigations as above

The investigations being of a preliminary nature, the experiment was kept very simple in form. The various treatments were given to the crops grown on small plots of 1/180 acre each. It may be pointed out that as compared to the years 1936-37 and 1938-39, the year 1937-38 was characterized by the prevalence of comparatively low temperatures during the main blooming periods of the crops, i.e. between November and February, and for this reason the results obtained during this year are somewhat different from those obtained during the other two years. This variation in the general run of temperatures was propitious from the point of view of these studies as it gave an opportunity for gauging the effect of variable weather on the rate of oil formation. The results obtained during the aforesaid three years are of great interest and, since they are likely to prove very useful in further research on these crops, they are presented here in the form of a short note.

Briefly put, the procedure adopted was as follows :—

Freshly opened flowers in sufficiently large numbers were tagged during each of the three different bloom periods which were taken to be as follows :—

Crop	Early bloom period	Mid bloom period	Late bloom period
Toria	First week of November	Last week of November	Middle of December
Brown *sarson*	Last week of December	Middle of January	First week of February

Samples of the developing ovules of known ages were obtained in all cases for the determination of moisture and oil content at regular intervals of ten days throughout the growing season. Measurements of length and breadth of 25 ovules were recorded in the case of each sample. The fresh and dry weights of 1,000 ovules were also determined in each case. The results obtained during these investigations are summarized in Tables I-III from which the following general conclusions can be drawn :—

(*a*) In all the years the maximum size of the developing ovules as determined by the greatest length and breadth was attained in about 40 and 50 days from the date of opening of flowers in *toria* and brown *sarson* respectively (Table I). Taking the average of all treatments in *toria* in the years 1937-38 and 1938-39 the length and breadth of ovules when 40 days old were 2·20 mm. and 1·92 mm. respectively, and in brown *sarson* the corresponding figures in the case of 50 days old ovules were 2·23 mm. and 1·99 mm.

(*b*) The fresh weight of developing ovules in both *toria* and brown *sarson* continued to increase at a rapid rate till about a month after fertilization, at the end of which time it turned the scale at a figure seven times the weight recorded in the case of ten days old ovules in *toria* and about 17 times in the case of brown *sarson*. Thereafter the weight remained more or less constant in *toria*, whereas in brown *sarson* there was a slight increase till the ovules were 60 days old. At full maturity, however, there was a decrease of about 33 per cent in the maximum fresh weight in brown *sarson*, which may possibly

be due to the desiccating effect of somewhat hot weather prevailing during March when brown *sarson* reaches maturity. The dry weight increased as the seed developed, obviously due to storage of greater quantities of food materials with an advance in development (Table I).

(*c*) Except for the first few days of seed (fertilized ovule) development the percentage of moisture decreased as the seed advanced in age. For example, in *toria* the moisture content in the case of all determinations made in all the years under consideration averaged 75·05 per cent when the ovules were ten days old. The average moisture percentage in the case of 20 days old ovules had increased to 80·73 and thereafter with an advance in the age of ovules it continued to decrease steadily till it reached the figure of 36·14 in the case of 70 days old ovules. Similarly, in brown *sarson* the average moisture percentage when the ovules were ten days old was 65·73, and in the 20 days old ovules it was 79·27 as against 12·77 when the ovules were 70 days old. Here a difference in the moisture content of 70 days old ovules of *toria* and brown *sarson* is noticeable which is presumably due to weather, which is mild and cold in the case of *toria* and somewhat warm in the case of *sarson* at the time when the ovules attain an age of 70 days in these two crops.

(*d*) The percentage of oil increased as the seed developed. For example, in the year 1936-37 the most rapid formation of oil in developing seed, expressed as the percentage of ether extract on dry basis, began when the seed was about 20 days old, and continued for another 20 days in the early and mid bloom periods in *toria* (Table II). The maximum percentage of oil was nearly reached at the age of 40 days, there being slight increase after that age till maturity. Similar conclusions were arrived at in the case of brown-seeded *sarson* in the mid and late bloom periods also. For instance, in brown *sarson* the oil percentage (average of mid and late bloom periods) in 40 days old seeds had increased to 44·88 from 4·56 found in the 20 days old seeds. Similarly in *toria* the oil percentage (average of early and mid bloom periods) in 40 days old seeds was 41·64 as against 5·71 obtained in the case of 20 days old seeds.

(*e*) In the case of early-formed ovules in brown-seeded *sarson* and late-formed ovules in *toria*, in all the three seasons, the increase in the oil content was very slow and the amount of oil formed was also much less (Table II). This fact could be attributed to the adverse effect of frost and cold which synchronized with the early bloom period in brown-seeded *sarson* and late bloom period in *toria*. For example, the oil percentage in the late bloom period (average of three years), when the seed was 40 days old, was 16·26 only in *toria*, as compared to 41·28 and 39·59 in early and mid bloom periods, respectively. In brown *sarson* the oil content in the case of ovules formed in early bloom period, when 40 days old, was 22·52 per cent, as compared to 37·40 and 41·07 formed in the mid and late bloom periods, respectively.

(*f*) Further confirmation of the effect of weather on the rate of oil formation was obtained in the year 1937-38 when, owing to the severity of cold during the mid bloom periods of both *toria* and brown-seeded *sarson*, the accumulation of oil in the case of all treatments was rather slow. The period of most rapid oil formation in the ovules during this year varied from about 30 to 60 days in *toria* and from about 30 to 50 days in brown-seeded *sarson* (Table III), as compared to about 20 to 40 days after flowering during the year 1936-37

(a year of normal temperatures). Taking the average for all treatments in 1937-38, the oil percentage, when the ovules were 40 days old, was only 19·64 and 27·38 in *toria* and brown *sarson* respectively, and reached the normal figure, viz. 42·57 and 44·38 when the ovules were 60 and 50 days old in *toria* and brown *sarson*, respectively. On the other hand, in 1938-39, when the temperatures were midway between those in the other two years under consideration, the rate of oil formation was greater than in 1937-38, the oil percentage (average of all treatments) in the former year when ovules were 40 days old being 36·79 and 38·94 in *toria* and brown *sarson*, respectively (Table III). In 1938-39 the fresh and dry weights of 1,000 ovules were also comparatively greater in all cases as compared to 1937-38. This is attributed to better development of ovules resulting from more suitable climatic conditions which prevailed during 1938-39. It is, therefore, concluded that under the conditions of these experiments the rate of oil formation in the two crops under consideration is mainly controlled by the meteorological conditions obtaining during the periods of seed development.

(*g*) The effect of manurial and irrigation treatments on the fresh and dry weights of 1,000 ovules and on the rate of oil formation was negligible.

Further work by the junior author, who is mainly responsible for the chemical investigations relating to this scheme, is in progress and it is hoped that with the accumulation of more data further light will be thrown on the various aspects of the problem concerned.

Acknowledgements

The results reported in this note form a part of the programme of work relating to a five-year oilseed research scheme in the Punjab, partly financed by the Imperial Council of Agricultural Research, and the authors take this opportunity of gratefully acknowledging the help received from the Council in this respect.

TABLE I

Relation between size, weight and moisture in developing ovules of toria *and brown* sarson (*average of all treatments*) *during mid bloom periods of their growth in 1937-38 and 1938-39*

Name of crop	Number of days after flowering	Length (mm.)			Breadth (mm.)			Fresh weight of 1,000 ovules (grams)			Dry weight of 1,000 ovules (grams)			Moisture percentage		
		1937-38	1938-39	Average	1937-38	1938-39	Average	1937-38	1938-39	Average	1937-38	1938-39	Average	1937-38	1938-39	Average
Toria	10	1·34	1·37	1·35	0·92	1·03	0·97	0·5096	0·8491	0·6793	0·1352	0·1948	0·1650	73·36	76·74	75·05
	20	1·90	2·00	1·95	1·59	1·64	1·61	2·3563	3·2188	2·7875	0·4877	0·6005	0·5441	80·15	81·32	80·73
	30	2·15	2·15	2·15	1·88	1·86	1·87	4·1963	4·9334	4·5648	0·8746	1·1693	1·0219	79·18	76·30	77·74
	40	2·22	2·19	2·20	1·96	1·89	1·92	4·4784	4·8966	4·6875	1·2643	1·8018	1·5330	71·79	63·09	67·44
	50	2·10	2·15	2·12	1·84	1·87	1·85	4·2342	5·2523	4·7432	1·6779	2·5325	2·1052	60·40	51·73	56·06
	60	2·06	2·15	2·10	1·79	1·86	1·82	4·2370	5·3743	4·8056	2·1778	3·1659	2·6718	48·59	41·09	44·84
	70	2·05	2·14	2·09	1·75	1·85	1·80	4·1349	5·2203	4·6776	2·4534	3·5074	2·9804	39·80	32·49	36·14
	80	...	2·04	...	...	1·78	...	...	4·7194	...	...	3·6119	...	...	23·62	...
Brown *sarson*	10	1·09	1·06	1·07	0·74	0·74	0·74	0·2620	0·3736	0·3173	0·1086	0·0945	0·1015	56·73	74·73	65·73
	20	1·87	1·85	1·86	1·50	1·47	1·48	1·7649	2·4564	2·1106	0·3933	0·4567	0·4250	77·47	81·08	79·27
	30	2·17	2·10	2·13	1·92	1·86	1·89	5·5154	5·6631	5·5892	1·0488	1·2846	1·1667	81·38	78·17	79·77
	40	2·20	2·18	2·19	1·98	1·90	1·94	6·2489	6·7205	6·4847	1·7532	2·3533	2·0532	71·88	64·79	68·33
	50	2·22	2·24	2·23	2·00	1·99	1·99	7·2854	7·0977	7·1915	3·3206	3·4435	3·3820	54·37	51·48	52·92
	60	2·23	2·20	2·21	1·98	1·98	1·98	7·1604	7·8480	7·5042	4·2752	4·7689	4·5220	40·15	39·18	39·66
	70	2·14	2·06	2·10	1·93	1·85	1·89	4·7005	5·5018	5·1011	4·3008	4·5150	4·4079	8·48	17·07	12·77

TABLE II

Oil percentage in developiny ovules of toria *and brown* sarson *during different periods of their growth in 1936-37, 1937-38 and 1938-39*

(*No manure and two irrigations*)

Name of crop	Number of days after flowering	Oil percentage on dry basis								
		Early bloom period			Mid bloom period			Late bloom period		
		1936-37	1937-38	1938-39	1936-37	1937-38	1938-39	1936-37	1937-38	1938-39
Toria	10	2·14	2·68	1·56	1·87	1·86	1·38	1·54	1·43	0·93
	20	6·25	7·62	8·69	5·17	2·90	4·22	5·10	1·47	1·83
	30	34·90	31·98	23·90	27·44	9·25	22·94	5·27	4·47	7·76
	40	40·29	38·62	44·94	43·00	32·92	42·84	13·16	7·48	28·13
	50	43·18	46·03	45·54	45·52	41·27	44·25	..	32·35	44·42
	60	43·83	44·01	46·38	46·30	43·06	47·31	..	45·51	45·72
	70	44·44	43·08	40·79	45·02	41·52	44·20	..	..	..
	80	45·94	43·13	44·32	..	..	..	..	..	..
Brown *sarson*	10	3·23	0·41	0·97	3·38	0·95	0·71	2·09	0·72	1·62
	20	3·80	1·32	1·62	4·86	1·66	1·64	4·27	2·28	4·28
	30	4·09	1·74	2·79	28·88	4·67	11·26	35·70	14·53	16·73
	40	27·24	12·19	28·12	43·88	31·19	37·12	45·89	36·18	41·13
	50	35·30	36·00	42·30	48·81	46·04	46·03	43·78	43·10	43·27
	60	50·40	47·13	41·55	..	46·59	43·21	..	..	41·54
	70	50·48	48·19	45·97	..	47·70	49·57	..	..	..
	80	49·70	51·12	45·48	..	..	44·11	..	..	..
	90	..	51·47	..	..	..	..	..	..	..

(..) No samples were available owing to the crop being over.

TABLE III

Oil percentage in developing ovules of toria *and brown* sarson *during mid bloom periods of their growth in 1937-38 and 1938-39 in different irrigation and manurial treatments*

Name of crop	Number of days after flowering	Oil percentage on dry basis in 1937-38						Oil percentage on dry basis in 1938-39					
		No manure and no irrigation	No manure but one irrigation	No manure and two irrigations	Farmyard manure and two irrigations	*Toria* cake and two irrigations	Sodium nitrate and two irrigations	No manure and no irrigation	No manure but one irrigation	No manure and two irrigations	Farmyard manure and two irrigations	*Toria* cake and two irrigations	Sodium nitrate and two irrigations
Toria	10	1·30	1·10	1·17	1·58	0·90	1·71	1·06	0·94	1·36	1·09	1·68	1·25
	20	1·35	1·80	1·60	2·66	1·49	2·36	3·45	3·94	3·23	3·42	3·43	3·14
	30	3·25	3·66	5·10	9·11	3·57	9·77	18·29	17·52	15·57	15·69	14·10	17·41
	40	17·72	14·10	18·32	24·30	13·78	29·63	36·42	38·16	37·07	37·30	36·90	34·92
	50	38·80	32·73	36·15	38·54	32·97	39·21	42·29	43·23	43·73	40·02	41·96	40·37
	60	44·49	40·99	42·92	42·54	40·67	43·80	41·84	45·29	43·62	42·65	41·45	45·09
	70	44·55	40·61	43·69	41·54	42·52	44·47	42·45	44·37	44·84	41·08	45·78	41·00
	80	...	...	...	...	...	...	43·86	43·01	42·74	41·55	41·43	43·68
Brown *sarson*	10	0·43	0·57	0·71	0·45	0·48	0·39	1·17	0·84	1·01	1·13	0·96	1·31
	20	1·13	1·23	1·75	1·29	1·29	1·39	1·94	1·47	1·72	3·05	1·67	3·27
	30	8·29	5·11	3·16	4·83	3·92	3·88	15·30	15·68	14·33	15·62	11·75	12·99
	40	29·52	28·56	26·76	27·97	26·64	24·82	41·07	36·05	40·26	38·33	36·43	41·51
	50	47·00	44·62	43·05	44·07	44·33	43·20	47·04	43·82	46·40	47·35	45·93	42·01
	60	45·50	47·72	45·88	45·74	48·39	45·69	47·20	50·26	48·25	49·50	47·99	47·98
	70	45·61	48·68	48·94	43·81	49·22	46·37	44·92	46·04	47·67	47·34	46·65	44·24

A NEW *CORTICIUM* ON ORANGE STEM

BY

JEHANGIR FARDUNJI DASTUR, M.Sc.

Mycologist to Government, Central Provinces and Berar, Nagpur

(Received for publication on 7 August 1939)

(With Plate I)

IN July 1938, when the writer was touring in Burhanpur (Nimar district), Central Provinces, a few orange trees (*Citrus aurantium*), about four years old, in an orchard were observed to have a white mycelial growth on the lower part of the stem facing south-west. From a distance it looked as if the stem was washed with lime. The growth was uniformly white and compact; at the margins the hyphæ spread out like a fan and were feathery in appearance. Though this white growth covered about 10 cm. of the circumference of the stem up to a height of about 30 cm. from the ground level, still the stem looked in no way unhealthy; there was no exudation of gum, no depression or drying or rotting of the bark; on scraping the bark below the white felt of mycelium the plant tissues were observed to be normal. The crown roots were also healthy and free from this mycelial growth.

Morphology

When the material collected at Burhanpur was examined in the laboratory at Nagpur the fungus mycelium was found to belong to a Basidiomycete, judging from the presence of club-shaped basidia bearing sterigmata.

In hand sections and in microtomic sections the mycelium was found to be wholly superficial; but the hyphæ filled the clefts or crevices formed by the cracking and scaling of the bark. In hand sections it was not always possible to get the film of the mycelium attached to its substratum, as the section of the film readily separated from the section of the bark. In microtomic sections the paraffin ribbon with the sections was often badly torn as in the mycelium were embedded minute particles of stone and dirt. At times along with this Basidiomycete were found hyphæ and pycnidia of a Diplodia, which was growing within the tissues of the bark; the basidiomycetous hyphæ often overran the pycnidia and the particles of stone and dirt, and completely covered them.

The mycelium can be roughly divided into three layers. The layer in contact with the substratum is thin and consists of long, delicate strands of hyphæ, running along the stem and parallel to each other; they are slender and of rather uniform diameter, about 3μ; they are sparingly septate and very little branched; they are compact but not twisted; they are without clamp connexions or anchor cells (Plate I, figs. 1 and 2); hyphal fusions have been observed, but very rarely. From some of these long hyphæ arises a broad

reticulum layer. It consists of profusely branched hyphæ with short, broad cells forming a loose network (Plate I, fig. 2); these cells are of varying shapes, such as globular, globoid, geniculated, cylindrical, etc.; they are 5·0-7·5 μ wide; the length is more variable, 8·3-21·6 μ; two neighbouring cells often fuse together. From this broad reticulum layer arises tangentially a row of cylindrical, erect and hyaline cells, the basal cells, 10·0-16·6 × 3·3-6·6 μ; on these basal cells are borne the basidia. Neither hyphal clumps nor gloeocystidia are present. The hyphæ are thin-walled and not incrusted.

Basidia and basidiospores

Basidia do not arise directly from the reticulum layer of cells; but they are developed from basal cells which grow laterally from the reticulate cells. The basal cell develops usually one basidium terminally (Plate I, figs. 3, 4, 7 and 10), but at times basidia may also be produced laterally (Plate I, figs. 6, 8, 9 and 12). The basidium is thin walled, hyaline and club shaped with a globular head; it measures 13·3-25·0 μ in length; the head is 6·6-10·0 μ in width where it is broadest; at the base the basidium measures 3·3-6·6 μ. From the basidium are developed four sterigmata; they are pointed at the apex and broad at the base; they are usually short, but at times they may be elongated; they are then very narrow in width. They are 2·5-6·6 μ in length and 0·83-2·5 μ in width at the base.

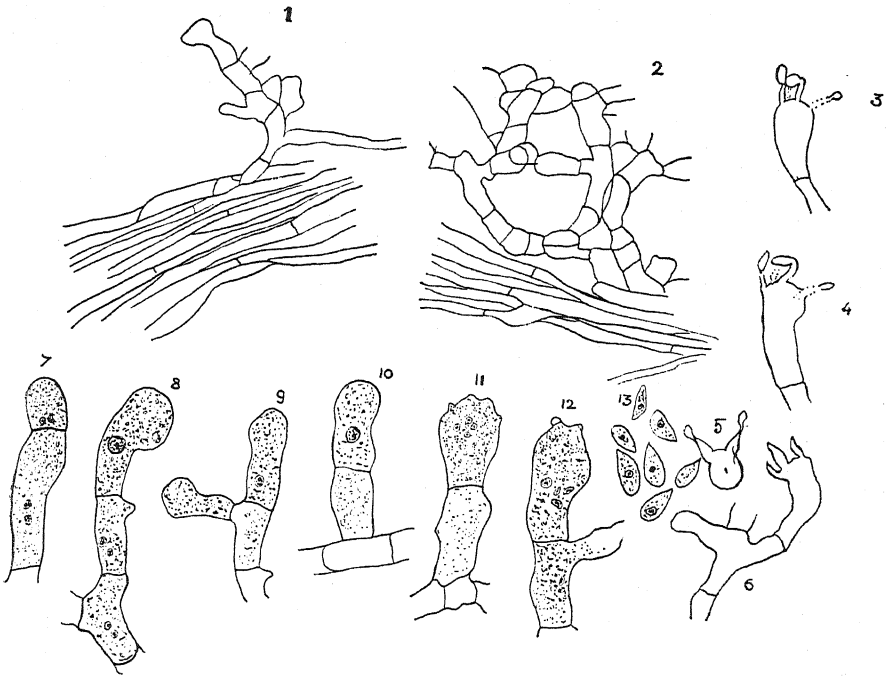
The basidia stain very deeply so also the basidiospores but the sterigmata stain very faintly. The basidiospores are oval in shape, pointed at the base and rounded at the apex (Plate I, fig. 13); one side is occasionally slightly flattened. They measure 6·0-13·8 × 2·5-7·0 μ, generally 8·3-10·3 × 3·3-5·0 μ.

Detailed observations on the cytology of the fungus have not been carried out because of the fresh material not being available in sufficient quantity.

The long hyphæ attached to the substratum have uninuclear cells; the cells forming the broad reticulum layer are binuclear; the nuclei are in pairs; at times two pairs of nuclei have been observed in some of these small, broad cells; the basal cells arising laterally from this reticulum layer are also binuclear (Plate I, figs. 7, 8 and 12); the very young basidium, the one which is being formed from the basal cells is also binuclear (Plate I, fig. 7); at a later stage the basidium which has still not developed the sterigmata is uninuclear the nucleus being larger than the nuclei in the basal cells and in the cells of the reticulum layer (Plate I, figs. 8, 9 and 10). As the basidium begins to form small protuberences on its head, which are the beginnings of the sterigmata, the single nucleus divides and forms four small nuclei (Plate I, figs. 11 and 12). In the basidium which had developed mature spores the cell contents are vacuolated; the nucleus has not been seen in such a basidium. The basidiospores are uninucleate (Plate I, fig. 13).

Taxonomy

According to the classification of Clements and Shear [1931] the fungus under study is a *Corticium*, as cystidia are lacking, spores are hyaline, pileus consists of one layer and is resupinate.



1, 2. Mycelium of fungus drawn from a transverse section of a citrus bark (×450) ; *3, 4.* Terminal basidia with sterigmata and basidiospores (×450) ; *5.* Head of basidium seen from above (×450) ; *6.* Lateral basidium (×450) ; *7.* Young basidium with its basal cell ; both are binucleate (×675) ; *8.* Basidium with a single fused nucleus borne on a binucleate basal cell arising from a short broad binucleate cell (×675) ; *9.* Terminal and lateral basidia (×675) ; *10.* Terminal basidium with one nucleus formed by the fusion of two nuclei (×675) ; *11, 12.* Basidia with immature sterigmata and four nuclei (×675) ; *13.* Basidiospore (×450)

Two species of *Corticium*, viz. *C. koleroga* (Cke.) v. Hohn and *C. salmonicolor* B. and Br., have been reported to occur on *Citrus*. In India the former has been known to do much damage to coffee, *Coffea arabica*, and is the cause of the well-known 'koleroga' disease of coffee, but has not been so far known to occur on any species of *Citrus*. The other, *C. salmonicolor*, is known throughout the tropics, including India, as the pink disease of *Citrus*, and also attacks many other woody plants.

C. koleroga attacks leaves, twigs and large limbs and fruits of *Citrus* in Florida. This fungus, according to Wolf and Bach [1927], produces brown rhizomorphs which 'can be readily traced from the sporophores backward along the petioles to the twigs and thence to the older wood'. On twigs and wood brown-coloured sclerotia are developed. The basidia arise as terminations of short, lateral branches. They measure 10·0-12·0 × 7·0-8·0 μ and have four, rarely six, sterigmata; the basidiospores are hyaline, flattened on the opposed faces, round above and tapered below; they measure 9·0-13·0 × 3·5-5·0 μ with 10·5 × 4·5 μ as the most common size. According to Narasimhan [1933] the basidia on the coffee host measure 8·5-12·0 μ in diameter and the basidiospores 9·1 × 3·4 μ; the length of the sterigmata is inconsistent, varying from 5·0 to 11·5 μ; the basidiospores are slightly flattened on one side, rounded at one end and somewhat pointed at the other.

The pink disease, as the name indicates, forms a salmon pink-coloured fungus growth on the host plant; the basidiospores measure 9·0-12·0 × 6·0-8·0 μ.

Both these species of *Corticium* form sclerotia.

The *Corticium* under study is therefore evidently different from the two species known to occur on *Citrus*. The difference lies in the hymenium being white (whereas the hymenium of *C. koleroga* and of *C. salmonicolor* is coloured), in the basidia being much larger, and the basidiospores smaller than those of the other two *Corticiums*, and in the absence of sclerotia.

If the key to the species of *Corticium* given by Burt [1926] is to be followed, then our species would belong to the same group as *C. bombycinum* (Sommerf.) Bresadola, *C. sociatum* Burt and *C. confluens* Fries. The characters of this group are:—Substance not appreciably coloured, gloeocystidia absent, hymenium white or whitish when growing, spores not globose but more elongated, large and more than 6 μ long.

Our species is clearly distinct from these three species.

C. bombycinum is in section 200-1,000 μ thick; the hyphæ are suberect, loosely interwoven and thick walled.

C. sociatum has small fructifications, 2-10 mm. long and 1-3 mm. wide; hyphæ are loosely interwoven near the substratum; a few embedded spores are present.

C. confluens has rather thick and waxy-membranaceous fructifications, 2-8 cm. long and 1-3 cm. wide; the fructifications are composed of ascending densely interwoven and agglutinate hyphæ.

Herbarium specimens and microscope preparations of the *Corticium* on the bark of an orange tree were sent to Dr Fawcett, Professor of Plant Pathology, University of California, for favour of examination and opinion. Dr Fawcett very kindly examined them and sent them to Dr J. N. Couch of the

University of North Carolina as the fungus ' was something with which he was not at all familiar '. Some more microscope preparations were sent to Dr Couch who very kindly took the trouble of examining them and reported,' I have examined the mycelium, basidia and spores and think they considerably resemble *Corticium* ..... Several species of *Corticium*, for example *C. koleroga*, *C. stevensii*, and *C. vagum*, have been reported as parasites on the leaves and stems of higher plants..... Furthermore, your species, though apparently related to the above-mentioned ones, seems to be distinct. I should like to see a piece of the dried specimen, since it is impossible to pass judgment on material preserved in formalin. However from the information I can gather, it seems to me that you would be safe in describing the fungus as a new species of *Corticium* '.

I therefore propose the name *Corticium album* n. sp.

Fructifications up to about 30 cm. long and about 10 cm. wide, smooth, shining, white, thin, resupinate and adnate, margin feathery ; in section 70-300 μ thick, composed of hyaline, little branched, thin-walled, sparingly septate parallel hyphæ, about 3 μ in diameter, compact, running longitudinally over the substratum and not twisted, giving rise to a broad layer of thin-walled, loosely interwoven, branching, hyaline hyphæ with broad, short cells ; from this reticulum layer arise laterally thin-walled, hyaline, cylindrical, basal cells 10·0-16·6 μ long and 3·3-6·6μ broad, from the basal cells basidia are developed terminally and also at times laterally hyaline, thin-walled, clavate, 13·3-25·0 μ long and 6·6-10·0 μ wide at the head ; sterigmata four, short, hyaline, broad at the base and tapering at the apex, 2·5-5 × 0·8-2·5 μ ; basidiospores hyaline, oval, rounded at the apex, pointed at the base, one side at times flat, 8·3-10·3 × 3·3-5·0 μ ; no gloeocystidia ; hyphæ not incrusted. On bark of living stems of *Citrus aurantium*.

My thanks are due to Dr H. S. Fawcett and Dr J. N. Couch for very kindly examining the material sent to them.

Summary

A new species of *Corticium* growing on the trunk of orange trees, *Citrus aurantium*, is described. The fungus forms a white film on the bark from the ground level up to a height of about 30 cm. ; the film is about 10 cm. broad. The growth is superficial ; it is not known to cause any damage to the tree.

REFERENCES

Burt, E. A. (1926). *Ann. Mo. Bot. Gard.* **13**, 173-354

Clements, F. E. and Shear, C. L. (1931). *The Genera of Fungi*, p. 161

Narasimhan, M. J. (1933). *Phytopath.* **23**, 875-86

Wolf, F. A. and Bach, W. J. (1927). *Phytopath.* **17**, 689-709

RESEARCH NOTES

DELAYED GERMINATION IN SESAME, *SESAMUM INDICUM*

BY

R. H. RICHHARIA

AND

D. R. DHODAPKAR

Oilseeds Research Laboratory, Nagpur, Central Provinces

(Received for publication on 13 September 1939)

(With one text-figure)

IN the course of our investigations on sesame selections, a great variation in the period of seed germination has been frequently observed in this laboratory. The normal period of germination in these isolations does not, as a rule, exceed four to five days, although some of them sprout in less than two days. But the remarkable feature of a particular type observed is its delayed germination. The seeds did not germinate even after putting them on a moist blotting paper for over seven months. They appear quite healthy with very rough, black and constricted seed-coat. When the black coat of such a seed is removed and the embryo is placed on a moist blotting paper in Petri dish, it becomes green, showing thereby its viability and proving that the seed-coat is chiefly responsible for the delayed germination.

The phenomenon of delayed germination has been studied in several groups of plants by various workers. They have established that there can be various causes bringing about this phenomenon, viz. genetical, physiological, morphological or environmental. In this connexion Crocker's recent paper [1938] may be consulted.

In the present case the cause of the delayed germination is the structure of the seed-coat. In the normal seed the coat consists of one or two layers of cells which are more or less rounded and loosely arranged, followed by a non-cellular membraneous layer.

In the case of seeds with delayed germination, on the other hand, the cells are elongated, arranged lengthwise (Fig. 1 L) and packed closely towards one side which makes the seed-coat unusually thick. Within these cells two regions can be distinctly marked, the outer (hyaline region, Fig. 1 D) and the inner (with striations, Fig. 1 E). On the outer surface of the cells, there exists a thick coating of some impervious substance (Fig. 1 A, B), which presumably obstructs the intake of water and oxygen. In the case of the normal seed, the loose arrangement of the cells and the absence of the impervious substance evidently allow the free passage of water and oxygen.

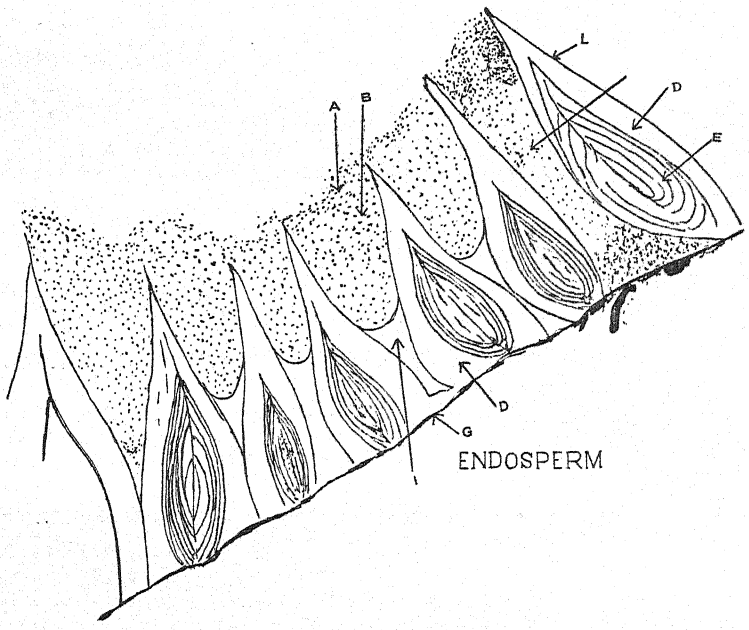


FIG. 1. T. S. of sesame seed showing delayed germination (×433)

A=Surface coating on the seed-coat

B=Impervious layer

C=Canal leading from outer surface to the endosperm

D=Hyaline part

E=Striation

G=Non-cellular layer inbetween the coat and the endosperm

I=Inter-cellular space

L=Elongated cell

An interesting feature in the structure of the seed-coat with delayed germination is that at places the impervious substance, referred to above, surrounding the seed-coat, penetrates through the inter-cellular space, thus forming a sort of canal (Fig. 1 C). At other places it stops half-way, as there is not enough continuous space leading to the endosperm (Fig. 1 I). The significance of this structure is not definitely known but presumably it has some connexion with the germination of the seed. When the seed finds a favourable environment, the substance in the canal must be subjected to gradual decay, thus making way for water and oxygen to enter. It may then bring about the germination of the seed, though the time taken may vary in individual cases, ensuring the distribution of this variety of sesamum over a number of seasons. This type of sesamum was commonly found at Dindori (Mandla district of the Central Provinces) in November 1938. Seeds were collected from some stray plants growing on the bunds of the fields at the Government Seed Farm, Dindori, and from the cultivators' fields. Such

plants are not harvested and they are regarded as wild sesamums by the inhabitants. Locally they are known as *baneli tilli* meaning wild sesamum. The seeds obtained are black with rough surface and with constrictions and exhibit delayed germination. Transverse sections also exhibit the seed-coat structures described above.

Such seeds are of no use to the farmer. Their presence in the cultivated area where the sesamums are grown is highly objectionable, as their spontaneous appearance in the pure strains will spoil the purity of the crop. While in the economy of nature these may be serving a useful purpose, they cause a distinct loss to the growers.

REFERENCE

Crocker, W. (1938). *Monthly Bull. Hort. Soc. New York*, March-April 1938

Phyllactinia Salmonii Blumer, reported as occurring on *Paulownia imperialis* in Japan. A brief description of the fungus is given below :—

Hypophyllus, very rarely caulogenus, mycelium cobwebby evanescent or persistent, thin and effused ; forming whitish spots or coatings on the under-surface of almond leaves. Perithecia usually scattered, rarely gregarious, large, lenticular ; when ripe 200-350 microns in diameter, orange yellow when young, dark brown at maturity ; cells of the perithecial wall obscure, more or less polygonal, 13-24 microns wide ; true appendages 6-12, equatorial, rigid, straight, aseptate, hyaline, acicular, 220-350 microns long, with bulbous base about 40 microns wide ; asci indefinite, subcylindrical to ovate-oblong, average 120 × 32—40 microns, slightly pedicellate ; ascospores two, variable in size, average 56 × 28 microns ; conidiophores 240-300 microns long, 8-12 microns thick, hyaline, septate ; conidia unicellular, clavate, average 76-x 10-24 microns.

REFERENCES

Blumer, S. (1933). *Die Erysiphaceen Mitteleuropas Beruckisichtigung Der Schweiz*, p. 401

Butler, E. J. (1900). *Mem. Dept. Agric. Ind. (Bot. Ser.)* **11**, 8

Butler, E. J. and Bisby, G. R. (1931). *Imp. Coun. of Agric. Res. Sci. Mono. No.* **1**, 35

Saccardo E. J. (1882). *Syll. Fung.* **1**, 5-7

Salmon, E. S. (1900) *Mem. Torr. Bot. Club*, **9**, 223-40

———— (1905). *Ann. Myc.* **3**, 493-505

NOTES

NOTIFICATION No. F.-46-20/38-A., DATED THE 6TH OF DECEMBER 1939, ISSUED BY THE GOVERNMENT OF INDIA, IN THE DEPARTMENT OF EDUCATION, HEALTH AND LANDS

IN exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendments shall be made in the Order published with the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320-35-A, dated the 20th July 1936, namely :—

I. In rule 12 of the said Order, after the words ' produced in India ', the words ' or in Burma ' shall be inserted.

II. In the Schedules annexed to the said Order

(1) for the Fourth Schedule the following Schedule shall be substituted, namely :—

Fourth Schedule (paragraph 12)

Certificate of origin for $\frac{\text{Indian}}{\text{Burman}}$ coffee beans or seeds

Name of consignor	Name of consignee	Gross weight	Number of packages	Mark of each package

Certified that the above consignment consists of raw coffee beans or seeds produced in India/Burma.

Signature of certifying authority.

No. of Railway Receipt or
No. of Bill of Lading.

Signature of Consignor.

(2) in the list of certifying authorities in the Fifth Schedule, after entry (*v*) the following entry shall be inserted, namely :—

' (*vi*) Customs Collector under the Government of Burma.'

(Sd.) J. D. TYSON,
Joint Secretary

NOTIFICATION No. F.-50-33/39-A., DATED THE 7TH OF DECEMBER 1939, ISSUED BY THE GOVERNMENT OF INDIA, IN THE DEPARTMENT OF EDUCATION, HEALTH AND LANDS

In exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to direct that the following further amendments shall be made in the Order published with the notification of the Government of India in the Department of Education, Health and Lands, No. F. 320/35-A, dated the 20th July, 1936, namely :—

In the said Order—

1. in paragraph 4 for the words ' potatoes and sugarcane ' the words ' potatoes, sugarcane and unmanufactured tobacco, either raw or cured,' shall be substituted,
2. paragraph 8 shall be renumbered as paragraph 8A, and after that paragraph as so renumbered the following paragraph shall be inserted, namely :—

' 8B. Unmanufactured tobacco, either raw or cured, shall not be imported into British India, unless, in addition to the general certificate required under Rule 5, it is accompanied by an official certificate, that it is free from *Ephestia elutelia* or that the pest does not exist in the country of origin.'

(Sd.) J. D. TYSON,
Joint Secretary

REVIEW

Plant hormones and their practical importance in horticulture. By H. L. Pearse. (*Technical Communication 12 of the Imperial Bureau of Horticulture and Plantation Crops, East Malling, Kent, England*) 1939, pp.88, bibl. 248. Price 3*s.* 6*d.*

INVESTIGATION of plant hormones and of their nature and properties still proceeds. Many of them have been isolated and chemically determined. Many now can be made synthetically, and thus made they are no less effective in stimulating growth. The history of this work has been told by Boysen-Jensen, Went and Thimann, Schlenker and others.

But whereas the academic botanist is primarily interested in how the plant grows, the practising horticulturist wants to know how he can increase or influence the growth made, and it is to him that the present memorandum should appeal most strongly.

Admittedly in the last few years articles on the propagation of particular plants from cuttings with the help of growth stimulants have been legion, but the man who spends most of his time tending plants has little opportunity to search the libraries and he will, therefore, be grateful to Dr Pearse for the tables in which nearly 1,000 instances are recorded of attempts made by different persons with varying success to root cuttings of plants of different plant species and variety with the help of named synthetic plant hormones. So far as is possible, the period and date of treatment, strength of solution, rooting medium, type of cutting, number of cuttings treated and number rooted are stated in each case.

In addition, he will find a clear account of the actual factors which affect root formation in cuttings, a review of published work on the practical use of synthetic plant hormones and notes on the practical methods found most useful by the author.

Unable to tear himself away from the fascinating subject, he will proceed with Dr Pearse to a consideration of the mechanism involved in induced root formation and note how increased efficiency of treatment may sometimes be realized by the use of such substances as vitamin B_1, carbohydrates, potassium permanganate, amino-acids, theelin and others.

He will learn of the surprising effects on plant growth brought to light by the curious scientist. Thus, hormone treatment definitely affects the germination of old or damaged seed, the growth of plants following treatment of seed, of the plants themselves or of their culture medium ; it also influences parthenocarpic development, fruit bud growth, fruit storage, framework control and rate of rooting in transplanted trees. Each one of these offers an interesting field of research.

And if he is still greedy for more, the comprehensive list of references shows him the way.

ORIGINAL ARTICLES

FINAL REPORT ON THE SCHEME OF INVESTIGATION ON THE WHITE-FLY OF COTTON IN THE PUNJAB

BY

M. AFZAL HUSAIN, M.A. (CANTAB), I.A.S.
Vice-Chancellor, University of the Punjab, Lahore

AND

K. N. TREHAN
Punjab Agricultural College, Lyallpur

(Received for publication on 25 September 1939)

GENESIS OF THE SCHEME

THE white-fly of cotton was first noticed in the Punjab in 1915. In 1922 it was reported as a serious pest of cotton in the Montgomery district, and casual observations were started by the Entomological Section of the Department of Agriculture, Punjab. By 1925 the insect had increased so greatly that it called for special attention. Finally in 1928 a special assistant was deputed for this investigation. In April, 1929, the Indian Central Cotton Committee sanctioned a senior scholarship for this work and appointed Mr. Kidar Nath Trehan for two years.

A three years scheme of investigation was sanctioned in 1931 at a total expenditure of Rs. 28,132. The scheme was further extended for two years and the total expenditure for these two years was Rs. 17,574. A further extension was given for writing up the results at a cost of Rs. 3,029.

A supplementary scheme for spraying trials was sanctioned for one year (1933-34) at a cost of Rs. 11,250. In the following year (1934-35) spraying trials scheme was sanctioned at a cost of Rs. 4,365. The Indian Central Cotton Committee have also sanctioned a sum of Rs. 4,100 to undertake sprayings during a bad white-fly year.

PUBLICATIONS

The results of the investigations carried out have been published in the following contributions :—

1. Afzal Husain, M., 1930.—' A Preliminary Note on the White-fly of Cotton in the Punjab ' :—*The Agricultural Journal of India*, Vol. XXV, Part VI, pp. 506-25
2. Afzal Husain, M. and Trehan, K. N., 1933.—' Observations on the Life-history, Bionomics and Control of the White-fly of Cotton (*Bemisia gossypiperda* M. and L.) ' :—*Indian Journal of Agricultural Science*, Vol. III, Part V, pp. 701-53

3. Afzal Husain, M., Trehan, K. N. and Verma, P.M., 1936.—' Studies on *Bemisia gossypiperda* M. and L. No. 3, Seasonal Activities of *Bemisia gossypiperda* M. and L. (the White-fly of Cotton) in the Punjab ' :—*The Indian Journal of Agricultural Science*, Vol. VI, Part IV, pp. 893-903

4. Afzal Husain, M., Puri, A. N., and Trehan, K. N., 1936.—' Cell Sap Acidity and the Incidence of White-fly (*Bemisia gossypiperda* M. and L.) on Cottons ' :—*Current Science*, Vol. IV, Part VII, pp. 486-7.

5. Afzal Husain, M., Trehan, K. N., and Verma, P. M., 1939.—' Economics of Field Scale Spraying against the White-fly of Cotton (*Bemisia gossypiperda*, M. and L.) in the Punjab ' :—*The Indian Journal of Agricultural Science*, Vol. IX, Part I, pp. 109-26.

The following papers have recently been submitted for publication :—

1. Nature and Extent of Damage caused by White-fly of Cotton.

2. Further Observations on the Bionomics of the White-fly of Cotton.

In view of the fact that a great deal of material obtained has already been printed and the rest is ready for publication, only a brief summary giving the main results is being presented.

Brief summary of the results of investigation

During the five years that the scheme has run, a thorough study of the external characters, life-history and bionomics of the white-fly of cotton has been made, its seasonal activities have been studied and the nature and extent of damage done by it to the cotton crop has been assessed. In addition insecticidal method of control has been worked out on a field scale. Incidentally our work has also established that the white-fly is not the main factor in causing ' cotton failure ' in the Punjab.

Distribution

An intensive study of the distribution of *Bemisia gossypiperda* has been carried out. This insect is widely distributed in the Punjab and has been recorded, from cottons or other alternative food plants, from almost all the districts of the province up to a height of 4,900 ft. above sea level. The severest of attack is, however, confined to Lyallpur, Jhang, Shahpur (Sargodha), Multan and Montgomery districts, the so-called ' canal colony tracts '. This white-fly probably occurs in other parts of India also but exact information on this point is lacking. In Sudan and certain parts of Africa it is known chiefly as a vector of the ' leaf-crinkle ' disease of cotton and tobacco.

Description of various stages

Egg.—Almost oval, stalked, light yellow when freshly laid, subsequently changing to dark brown.

Nymph of 1st instar.—Oval, light yellow, margin of body with 16 pairs of bristles. Legs functional.

Nymph of 2nd instar.—Oval, depressed, pale greenish yellow, legs degenerate, without any joints.

Nymph of 3rd instar.—Shape and colour identical with nymph of 2nd instar.

Pupa.—Body slightly convex, deep yellow. Spines on the back variable in number.

Adult.—Body yellow with two pairs of white wings. Eyes constricted in the middle. Hind legs longer than others. [In the male abdomen (' belly ') tapers posteriorly.]

Behaviour of adults

(*a*) *Attraction of adults to coloured lights.*—According to Lloyd adults of *A. vaporariorum* are attracted to yellow-coloured light. A similar study was carried out with *B. gossypiperda* and it was found that they showed the greatest attraction for yellow-green coloured light and next highest for yellow, the least number of them was attracted to bright red, orange red, dark green and purple coloured lights.

(*b*) *Range of flight.*—*B. gossypiperda* feeds on a large number of plants. It is, therefore, difficult to study its range of flight unless the locality in which such observations are made is free from this pest. Observations, however, were made to determine the height which this pest attains during flight. The insect has been found at a height of 40 feet above ground level but as it is carried away long distances by wind, it is not improbable that it may be found at heights greater than that recorded by us.

Life-history

Bemisia gossypiperda produces about 12 broods in a year but the generations overlap, and, therefore, all stages of the pest are met with throughout the year. It breeds practically all the year round, often parthenogenetically, the unfertilized eggs producing only males. Eggs are laid singly on the leaves and each is inserted in the tissue by a short stalk. In confinement they may also be laid on the stumps of defoliated seedlings. In this case the nymphs die off shortly after hatching. Laboratory observations show that the top and middle leaves are preferred for oviposition, for 51·5 per cent and 46·7 per cent respectively of the eggs were laid on them, while 1·8 per cent only were laid on the lower leaves. Much the same kind of behaviour is also noticed in the field. It has also been observed that in nature eggs are laid invariably on the lower side of a leaf.

A single female may lay, on an average, 28 to 43 eggs during its oviposition period, which may last from 2 to 18 days : she lays six to eight eggs in 24 hours. Temperatures between 33 and 37°C. are the most suitable for oviposition, no eggs were laid at 19°C.

The incubation period varies from 3 to 33 days depending upon the temperature. During the season of the growth of cotton plants, i.e. April to September, eggs hatch in three to five days, during October to November in 5-17 days and during February to March in 7 to 16 days. In December and January the incubation period may be as long as 33 days.

The insect has three nymphal and a pupal instar. The duration of the three nymphal instars varies from 8 to 14 days from April to the end of September but from October onwards this period is considerably prolonged and ranges from 17 to 73 days. Unlike the Citrus *Aleurodidæ* the pupal stage of *Bemisia gossypiperda* is very short and occupies only two to eight days. The adults, which emerge, as a rule, during the day time, do not live very long in summer and in captivity their life lasted two to five days. During November, however, some adults lived up to 24 days. A complete life-cycle from egg to adult may occupy from 14 to 107 days. During April-September it occupied only 14 to 21 days. The shortest life-cycles were observed during August. From October onward the life-cycle is much prolonged and in one case during these investigations it extended up to 97 days between November-February.

Food plants and seasonal history

Bemisia gossypiperda is polyphagous and a list of its host plants in the Punjab includes no less than 44 species, both cultivated and wild, belonging to about 13 families. Irrespective of any preference for any of its food plants, the density of white-fly population on a particular host is influenced to a large extent by its proximity to the cotton fields infested by it, protection from wind, adequate humidity and, what is probably most important of all, radical changes in the composition of cell-sap of the leaves of the plant at different periods of growth indicating the physiological state of the host. At times, however, the intensity of infestation on certain of the host plants increases sporadically.

In general the white-fly undergoes three phases of migration during the course of a year :

1. During November when the cotton crop is maturing and the leaves are drying up and shedding, the white-fly population falls on this plant and infestation starts on such alternative host plants as rape (*Brassica napus*), cauliflower (*B. oleracea*), turnip (*B. rapa*) and potato (*Solanum tuberosum*), among the cultivated plants and *Sonchus* spp., *Euphorbia* sp. and *Convulvulus arvensis* among the commoner of the weeds. From December onwards the number of adults falls considerably, but the immature stages remain on these alternative hosts throughout the winter. The adults commence emerging from about the end of January and multiply once again on the winter host plants already named above.

2. By the end of March the white-fly migrates to its spring hosts, namely, *Cucumis melo*, *Citrullus vulgaris*, *Cucumis sativus*, *Lagenaria vulgaris*, etc. where rapid multiplication takes place. From April onwards ratoon cottons, *Nicotiana tabacum*, *Hibiscus esculentus* and *Althea rosea* are also severely infested. During April and May ratoon cottons and melons form the most important breeding centres.

3. The white-fly makes its appearance on the new cottons early in May soon after the crop has germinated, but the attack at this stage is extremely low as compared to the other host plants. From June, however, partly because of migration from the alternative host plants, but mainly on account of the rapid multiplication of the pest, the intensity of attack increases enormously on the new cotton crop. The data collected have established the fact that the period of the severest attack on cottons extends from June to August

after which the infestation, as a rule, declines abruptly. To determine the status of various host plants as the true food-plants of *B. gossypiperda*, a series of cross-inoculations was carried out. It was found that this insect is not so unorthodox as to feed on all and sundry plants. For example, repeated attempts were made unsuccessfully to breed it on *chari* (*Andropogen Sorghum*). Further, it has been observed that the pest prefers certain plants for oviposition and this preference depends upon the time of the year and its own period of migration.

Comparative infestation of different varieties of cotton

It has been stated commonly that the incidence of white-fly attack is higher on the broad-leaved varieties (Punjab-American) than on the narrow-leaved varieties (*desis*). A census of white-fly nymphs and eggs taken on four varieties, 289-F and 4-F, representing the Punjab-Americans, and *mollisoni* and *sanguineum*, representing the *desi* varieties, was taken from 1931 to 1933. The results indicate that the insect shows no selective preference in infesting varieties of cotton all of which are liable to be attacked almost equally severely. The *Desi* varieties, in general, are comparatively more infested during the growing period, i.e. till about the end of August, after which the attack increases on the American varieties. The attack may increase once again on *desi* varieties towards the end of the season when they may begin to sprout.

During 1934 and 1935 some new selections of the American types were compared with *mollisoni*, 4-F and 289-F. During the growing period the white-fly infestation was significantly higher on the *desi* variety, whereas during the fruiting period it increased on the American types. While determining the cause of this change-over of infestation, it was noticed that the incidence of attack corresponded with the trend of the *p*H curve, indicating partiality towards higher values. The infestation, however, was not affected immediately, but after some time, because the nymphs, being fixed on the leaves, must take some time before the effect of the change in *p*H can be appreciated by them. This finding is of considerable importance in absolving this pest of the blame of being the main cause of cotton failures because it is only the Americans that fail.

Incidence of white-fly attack in relation to amount of water applied

The type which received the largest number of irrigations and, consequently, the maximum amount of water, had on an average, the lowest white-fly attack. On the other hand, the types which received restricted irrigations with a corresponding minimum supply of water, were comparatively severely infested.

Influence of date of sowing and of manures on the incidence of white-fly attack

The incidence of attack on the early-sown crop was found to be comparatively higher up to September after which it was practically uniform on all the sowings. There is not much difference between the cotton sown between 1st May and 1st June, but the cotton sown later escapes the attack of the pest. The intensity of attack was slightly lower on manured plants but plants treated with ammonium sulphate or super phosphate early in the season (June

or July) at the rate of 1·5 maunds per acre showed comparatively less attack. It was also observed that the relative infestation was significantly lower in the plots treated early with nitrogenous manures both in the rich and poor soils. On the other hand, early manuring in poor soils and late manuring in rich soils yielded better out-turns.

Climatic conditions and condition of the host plant and white-fly attack

A correlation between the white-fly population and the meteorological condition of a locality points to the conclusion that the attack is highest in areas (canal colony tracts) of high temperature and scanty rainfall. On the other hand, the attack is lowest in the south-east and the north-west Punjab where rainfall is high or the climate is rather temperate.

Some experiments were also performed to study the condition of the host plant, as influenced by changes in the soil, in relation to its infestation by the white-fly. Although very definite conclusions are not possible, the evidence available seems to show that white-fly attack was relatively low on plants grown in soils of slightly lower *p*H value (6·64 brought about by addition of ferrous sulphate) as compared to those grown on more alkaline soils (8·55 ; treat ment with sodium carbonate). The vegetative growth of the plants may indirectly affect infestation. With ferrous sulphate treatment, however, the attack was comparatively lower although the plants were below normal in their vegetative growth. Further, the highest number of bolls and relatively low shedding were noticed on the plants treated with ammonium sulphate or sodium nitrate. The least alkaline soils gave very poor yields in spite of low attack of the white-fly, but the highly alkaline soil also gave a poor yield with a correspondingly higher infestation.

Although there seems some possibility of preventing an attack of sucking insects through soil treatment, the full possibilities of controlling this pest by this method remain unexplored.

Nature and extent of damage

Unlike most sucking insects, *Aleurodidæ* do not produce any visible injury, such as spotting, crinkling or any other deformation on their host plants. *Bemisia gossypiperda* has been regarded as the vector of leaf-crinkle of cotton in Sudan and a probable transmitter of leaf-curl in *Zinnia* at Dehra Dun and of tobacco at Pusa. In the Punjab up to the present time the white-fly infestation of cotton is not associated with leaf-crinkle of any type whether caused by a virus or any other toxic agency. Indeed, leaf-curl or leaf-crinkle of cotton as a virus disease has not so for been discovered in these parts. Nor is there any evidence that the white-fly of cotton is in any way associated with the recently discovered ' smalling ' disease of cotton in the Punjab.

The obvious results of white-fly attack are : (1) drain of the plant juices, which results in lowering the vitality of the plants, (2) development of a black fungus on the honey-dew which is exuded by the nymphs and pupæ and drops down to the lower leaves, thereby interfering with the photosynthetic activities of the plant.

In the absence of any mechanical injury to the plant tissues the effects of white-fly infestation were studied in relation to the physiological changes connected with the growth and reproductive activities of the host plant.

The work carried out at Lyallpur throughout the period of this scheme has shown that the infestation of a plant by the white-fly is detrimental in all its stages, viz. the growth period, the time of flower and boll formation and of lint and seed development. Further, the effects of the attack are more serious in the later part of the growing period—the flowering stage, when important changes and adjustments in the vital nutrients are going on in the tissues of the plants and making it most susceptible to injury.

During the period of severe infestation the vegetative growth is checked and in most serious cases may almost be stopped. Boll formation becomes indirectly proportional to the intensity of attack; whereas the shedding and bad opening remain in direct proportion. The bolls produced by the uninfested plants were well-developed and yielded a maximum weight of *kapas*. The severity of infestation, particularly when it appears late in the growing season, lowers the yield of lint and in all respects affects the plants adversely.

An analysis of the above conditions has shown that infested plants are deficient in their moisture percentage with a corresponding increase in dry matter. Attacked plants also carry a higher carbon-nitrogen ratio, a condition which has been shown to retard both vegetative and reproductive growth. Experiments performed in 1932, 1934 and 1935 definitely indicated that a relatively higher infestation by the white-fly not only decreases the dry weight of the plant, but also leads to slightly greater shedding of leaves, floral buds, flowers, etc. It was also determined that the maximum loss in the dry weight of the vegetative portion takes place during August-September. From October, however, the loss is manifested in the weight of the reproductive organs.

Mineral ash.—About 36 per cent more ash was produced by the healthy plants of which 11·3 per cent was estimated to have been transported to the bolls.

Fat.—The percentage of fat was comparatively higher in the foliage of healthy plants, while that of carbohydrates was relatively higher in the foliage of infested plants throughout the season.

Analysis of healthy and infested plants in 1932 showed that (1) nitrogen is higher in the foliage of the uninfested cotton plants till the middle of August after which it may rise in the foliage of the infested plants : it is considerably higher in the bolls of the uninfested plants, (2) healthy plants, on the whole, produce more total nitrogen than the infested ones in which the transport of nitrogen, ash and fat from the vegetative to the reproductive organs is markedly reduced. It is surmised, therefore, that the reduction of bolls which occurs on the infested plants is the result of some dislocation in the carbohydrate and protein balance.

Control

Predators and parasites.—The third instar nymphs and pupæ of *Bemisia gossypiperda* have been found parasitized by Chalcid parasites which deposit

their eggs within the body of their hosts, the parasites completing their life-cycle in six to seven days in August. Larvæ of a lacewing fly (*Chrysopa* sp.) and of a Coccinellid beetle (*Brumus*) have been observed feeding on the adults of the cotton white-fly and observations also showed that the number of adults killed by an individual grub of *Brumus* or *Chrysopa* sp. far exceeds that which is actually required for its feeding. These enemies, however, do not afford any satisfactory control.

Cultural methods.—The cultural practices, such as altering the dates of sowing and the amount of water applied, do not hold out much promise of materially reducing infestation by this insect. Clean cultivation and safe disposal of alternative hosts in the cotton off-season will, however, to a certain extent reduce the extent of white-fly attack. Proper manuring at the right time may help the plants to recover from the damage caused by the white-fly.

Spraying.—Small-scale spraying experiments were conducted against this pest during the years 1929-1932. Results of single and double sprayings were compared. Double sprayings once in July and again in August proved very effective. A single spraying in September or double spraying with the 2nd treatment falling during that month resulted in a relatively much lower increase than even in case of a single spraying in July or August. Late spraying in September causes additional flower and boll shedding and ultimately affects the yield adversely. Since these spraying operations gave encouraging results, it was felt necessary to estimate the efficacy and economics of this method of control on a field scale. This was made possible by a grant of the Indian Central Cotton Committee for spraying trials during 1933.

Extensive spraying operations were conducted from the 10th July to 31st August on the British Cotton Growing Association Farm, Khanewal, and at the Military Farms, Okara. These spraying trials were repeated during 1934 to confirm the previous results and to improve the technique of spraying. Both *desi* and American cottons were treated in 1934, when the operations were extended to Sargodha as well. Most of the area under these field trials was sprayed with rosin compound but a number of other insecticides, such as rosin soap, fish-oil soap, tobacco decoction, kerosene oil emulsion and lime sulphur, were tested on smaller scales. Rosin compound proved to be the most satisfactory insecticide.

In all 1873 acres of cotton crop were sprayed during 1933 and 2640 acres in 1934. Machines of the type of cart sprayer proved useful as their working was very easy and economical, but the Hardie sprayer with two horse power motor pump yielded very satisfactory results, both with regard to the mortality of the pest and the cost of spraying. These cart sprayers can only be worked when the crop is sown in lines and has not grown very tall. To test the possibilities of employing a sprayer which kept outside the field—an orchard power sprayer—with pipes laid in the field was used. It gave a kill of 95·7 per cent of adults and 93·9 per cent in nymphs and pupæ—the maximum obtained, but it was cumbersome and uneconomical.

The maximum quantity of insecticide consumed in 1933 was 58·2 and 43·3 gallons per acre with Hardie and Sapom respectively : the orchard power sprayer consumed 68·4 gallons per acre at Okara.

The average time required for spraying one acre of cotton was 12·4 to 26 minutes, depending upon the machine.

The cost of spraying with rosin compound varied on the whole, from Re. 1-2-3 per acre with the Sapom sprayer to Re. 1-7-9 with the Hardie sprayer and Rs. 2-9-9 with the orchard power sprayer during 1934. These costs were lower than those of 1933 by 15·5 per cent, 8·1 per cent and 21·1 per cent respectively. The cost was comparatively higher with other insecticides under trial. It is possible, however, to reduce the cost still further by paying more attention to details connected with these operations.

Spraying *desi* cotton during the month of July and American cotton during August increased the yield. The average increase in yield per acre by spraying was 0·5 to 2·0 mds. for American when sprayed in July and August and about the same for *desi* when sprayed in July. Spraying of *desi* cottons in August, however, yielded negative results. It was found that spraying must be done before the flowers appear.

A NEW PEST (*ACANTHIOPHILUS HELIANTHI* ROSSI, TRYPETIDAE) OF SAFFLOWER IN INDIA

BY

HEM SINGH PRUTHI, M.Sc., Ph.D. (CANTAB), F. N. I.

Imperial Entomologist

AND

H. L. BHATIA, M.Sc.

Imperial Agricultural Research Institute, New Delhi

(Received for publication on 24 August 1939)

(With Plate III)

INTRODUCTORY

ABOUT the middle of March, 1939, in the experimental plots of safflower (*Carthamus tinctorius*) of the Imperial Economic Botanist at New Delhi, some of the flower buds presented a diseased appearance, the chief symptom of which was an odorous juice oozing out from the apical region of the buds. Such buds were found to contain dirty-white maggots of a fruit fly which has been identified as *Acanthiophilus helianthi* Rossi. This is the first record of this genus and species from India.

The pest was very active during March, April and May and caused serious damage in both early and late sown varieties of safflower, the infestation being as high as 90 per cent. The young florets were damaged by the maggots with the result that the buds opened partially or did not open at all.

As the cultivation of safflower is being considerably extended in India for the dye obtained from its flowers and for the oil obtained from its seeds, there is danger of the spread of the pest which can be carried in the pupal stage mixed amongst the seeds from one place to another.

Detailed observations on the biology of the pest have been taken during the last spring and summer. As the pest is new and is of considerable potential importance, the results of investigation so far obtained are being published, so that workers in other regions of India may be able to recognize the pest if it occurs there.

DISTRIBUTION AND HOST PLANTS

Chiefly through the courtesy of Mr. Munro, Entomologist, Department of Agriculture, South Africa, we have been able to obtain the following information about the distribution of *Acanthiophilus helianthi* Rossi in other countries :—

The species was originally described by Rossi in 1790 and has been referred to in literature as *Trypeta eluta* by several workers [Meigen, 1826 ; Efflatoun

1924, etc.]. The species is recorded from the Canary Islands, the Mediterranean region, Central Europe, North Africa, Egypt, the Sudan, Erytrea, Asia Minor, Persia and Central Asia. The recorded host plants are : *Centaurea* spp., *Cnicus lanceolatus*, *Silybum marianum*, *Onopordon illyricum*, *Amherboa lippi*, *Leuzea conifera* and *Carthamus tinctorius*. According to Hendel [1927], the maggots as a rule live in the flower heads, producing galls. but they are also found at times in the stems, as in the case of *Cnicus lanceolatus*. Most of the host plants listed above seem to be more or less weeds, with the exception of *Carthamus tinctorius* (safflower), with regard to which Hendel [1927], reports a record by Handlirsch of rearing the maggots from the flower head but does not state the locality.

As stated already, there is no previous record of the occurrence of *A. helianthi* from India, but probably the fly recorded attacking seeds in plants of safflower [Rati Ram, 1927] in the Central Provinces was this species.

Nature of damage

The flies were observed on wing in the field for the first time about the middle of March and infestation of the safflower buds by the maggots was evident a week afterwards. The maggots feed upon the essential organs of the florets and even bore into the thalamus. The infested bud begins to rot and the fluid thus produced oozes out from its apical portion and gives it a damp appearnace (Plate III, fig. 2). If such a bud is squeezed between the fingers, the fermented liquid along with one or two maggots come out of the tip of the bud. Furthermore, in advanced stage of attack, the florets become black, presenting an emaciated and withered appearance (Plate III, fig. 3.)

Incidence of the pest in various varieties

Out of the 34, varieties grown for experimental purposes by the Imperial Economic Botanist, the felted varieties (No. 11—15) and the varieties No. 20-22, 30 and 34 were attacked more than the rest, early in the season, viz., from the third week of March up to the end of the first week of April. All the varieties named above are much less spiny and are late in flowering. The second generation of the pest which lasted during the second and third weeks of April was rather small in numbers, probably on account of the activity of the parasites and the predator described hereafter. In the fourth week of April the third generation of the fly was in evidence and the incidence increased rapidly in all the varieties, the degree of infestation being again higher in the felted and the less spiny varieties as compared to the spiny ones. A statement of the attack of the pest in different varieties during the season would be found in the appendix.

It may be added that incidence in the wild safflower which is very spiny was lower than in any of the spiny cultivated varieties. However, after the first week of May when all the cultivated varieties had been harvested, the pest was found in abundance in the wild safflower, which was in flower and was found growing along the field drains and elsewhere in uncultivated areas.

Life-history and description of various stages

The flies were observed laying eggs in the field from sunrise till about noon. For oviposition the fly prefers a young bud, walks over its surface several times, pricks it at a number of places with its black and rather shiny ovipositor, the duration of each pricking being about 5 seconds, and finally selects a place where it lays the eggs. The behaviour of the female in the actual process of oviposition was observed to be different in several respects from other common fruit flies, viz., *Dacus* spp. During this process which lasts about two minutes, the female slightly bends the abdomen, its ovipositor in action making an obtuse angle with the surface of the bud. It is entirely motionless during egg-laying, appearing as if it is dead. After laying eggs, which may vary in number from 6 to 24 in a cluster, the female lashes its ovipositor up and down in the air, cleans it with its hind pair of legs before retracting its extended parts into its basal portion.

The eggs are laid in punctures either on the innerside of a bract belonging to the innermost row of bracts of the involucre (Plate III, fig. 4), or on a membraneous calyx leaf of one of the peripheral ray florets or on the corolla of a ray floret. Usually one and in some cases two egg-punctures are observed on one bud (Plate III, fig. 2). The egg (Plate III, fig. 5) is white when freshly laid. It is cylindrical, elongated (1·12 mm. × 0·2 mm.), truncated and drawn out at one pole and narrowed at the other pole which has a minute knob. The drawn-out region of the egg is hyaline. The chorion is marked all over, except at the truncated pole, with elongated, hexagonal areas converging towards the opaque knobbed end. During hatching, which takes place usually in the morning hours in the laboratory, a slit appears at the hyaline pole and the young maggot wriggles out (Plate III, fig. 6). The young maggot begins to feed on the florets at once. It is 0·75 mm. × 0·2 mm., creamy-white, cylindrical and narrow in the head region (Plate III, fig. 7). The segments are clearly marked. The cephalo-pharyngeal skeleton is slightly chitinized. The maggot at this stage is metapneustic, only the posterior pair of spiracles being present. Each spiracle has two slits.

The full-grown maggot (Plate III, fig. 8) measures 5·0 mm. × 1·5 mm. It is light ochraceous, cylindrical, broad in posterior region and gradually tapering in the anterior and pointed at the head. The posterior end of the maggot is almost truncated. The head is pear-shaped, with the oral opening situated on the ventral side and bears :— (*i*) a pair of antennae ; each antenna being composed of apparently one joint which is minute, cylindrical and has a knob-like apex (Plate III, fig. 10, *an.*) ; (*ii*) maxillary palps : each palp is situated just below the corresponding antenna and has three to four papilli-form sensoria (Plate III, fig. 10, *m. p.*) ; (*iii*) the cephalo-pharyngeal skeleton, which is a highly chitinous structure and extends up to the first thoracic segment (Plate III, fig. 11). It is composed of the following :—

(1) A pair of oral hooks or mandibular sclerites or mandibular hooks, which are furnished each with two strong teeth ; the apical tooth is curved and the pre-apical tooth, which is smaller and less curved, is directed downwards and somewhat backwards.

PLATE III

FIG. 1. Healthy bud (Natural size)

FIG. 2. Damaged bud (Natural size)

FIG. 3. Vertical section of damaged bud (Natural size)

FIG. 4. An egg mass (×4)

FIG. 5. The egg (×16)

FIG. 6. The hatching out maggot (×16)

FIG. 7. The newly hatched maggot (×16)

FIG. 8. The Full-grown maggot (×10)

FIG. 9. The anterior spiracle of one side (×192)

FIG. 10. The antenna and maxillary palp of one side (highly magnified)

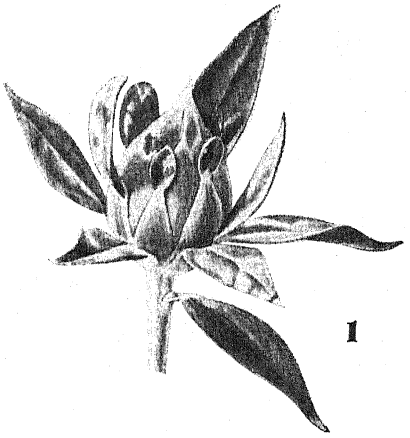
FIG. 11. The cephalo-pharyngeal skeleton (×80)

FIG. 12. The posterior spiracles (×100)

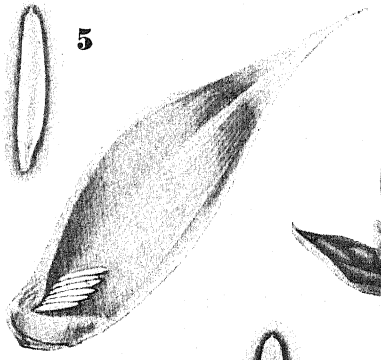
FIG. 13. The pupa (×10)

FIG. 14. The female fly (×10)

FIG. 15. The head of the imago (×10)

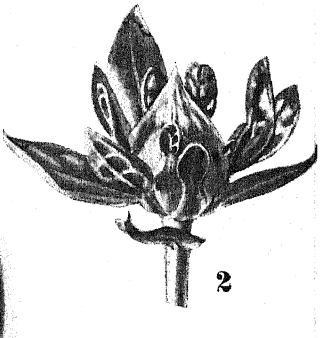


1

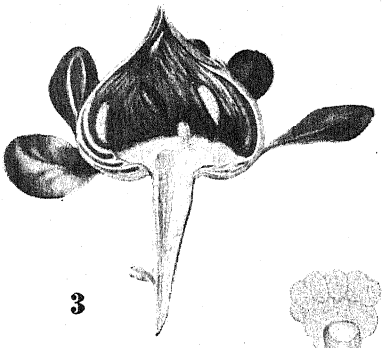


4

5



2



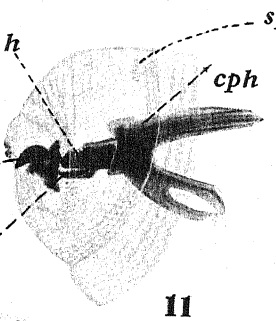
3



6



7



11



13



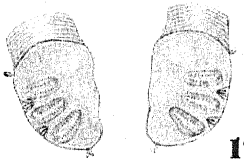
9



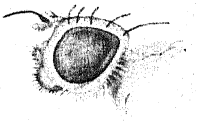
8



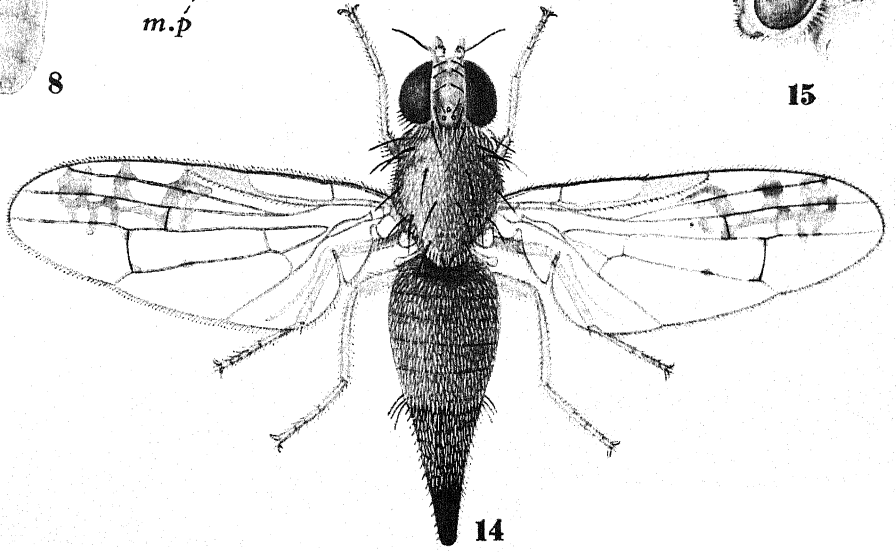
10



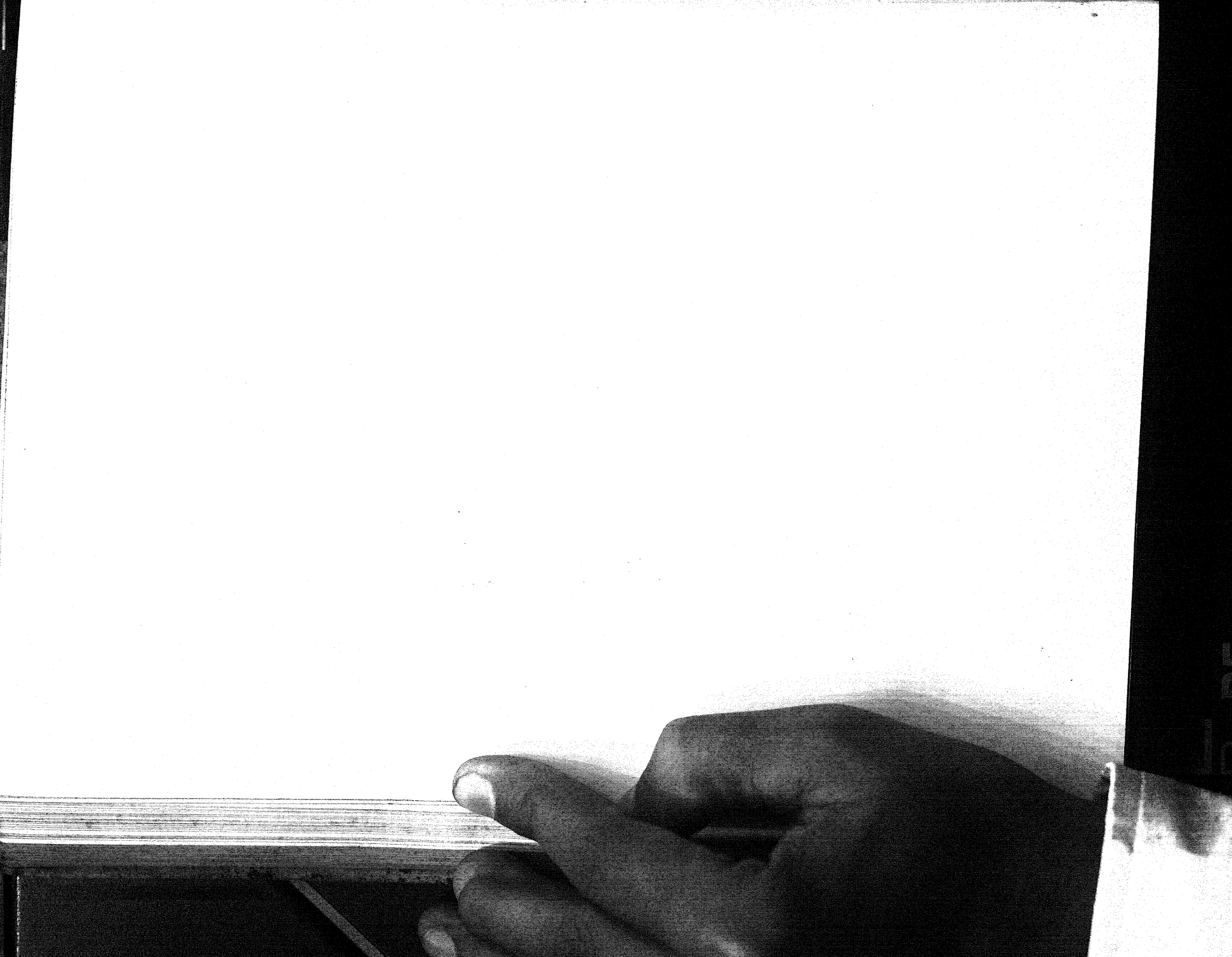
12



15



14



(2) A pair of hypostomal or intermediate sclerites (*h*). They are elongated, the broad posterior margin being one and a half times or twice the narrow anterior margin. A pair of rod-shaped sub-hypostomal sclerites (*s. h.*) connects these sclerites with the oral hooks.

(3) Cephalo-pharyngeal sclerite (*Cph.*) which is made up of two shafts united anteriorly, the free portions being forked. Posteriorly, each branch of the fork is further divided into two appendages.

The body of the full-grown maggot has besides the head, 11 visible segments, three thoracic and eight abdominal. At this stage the maggot is amphipneustic, the anterior and posterior spiracles being borne by the first thoracic and the last body segment respectively (Plate III, figs. 8, 9, 12). The long tracheal tubes are visible within the integument. The anterior spiracles are cup-shaped, the margin of each spiracle being fringed with six oval lobes. The posterior spiracles are almost reniform, each possessing three elongated oval slits which are notched at the peripheral end. The inner walls of the slits are chitinized and fimbriated. In each of the inter-spiracular areas there are one to four very minute hyaline lanceolate processes. The pseudopods, which are clearly seen in the abdominal region of the maggots of several species of fruit flies especially of the subfamily Dacinæ, are not distinct in this species. Girdles of four to eight rows of minute conical spines with their apices directed backwards are found in the inter-segmental region of the body. There are fewer rows of spines in the thoracic than in the abdominal segments. The maggot is not capable of jumping, a habit which is so characteristic of the maggots of other Trypetid flies, particularly those infesting fruits.

Pupation generally takes place in the flower bud, the puparia being rarely met with in the soil. The puparium (Plate III, fig. 13) measures 4·25 mm. × 1·75 mm. It is barrel-shaped, black with a metallic tinge. There is a small depression in the thoracic region. The larval girdles of spines and the spiracles are retained and occupy the same positions as in the maggot.

The flies emerge and leave the infested flower bud through small holes on its surface, previously made by the full-grown maggot, each exit hole being about 2 mm. in diameter. The newly emerged flies are rather sluggish, their eyes emerald-green (Plate III, fig. 15) and the body ash-grey. The greyish markings on the apices of wings are not well developed. The flies soon become active and resume their normal appearance within a few hours in the field. They are ash-coloured, bristly, with reddish-brown frons and light brown legs. The male is smaller in size than the female (Plate III, fig. 14) which is about 6·5 mm. in length. The flies are lovers of sunshine flying about flower heads of safflower from sunrise to sunset.

The duration of various stages (average of five readings) in April in the laboratory having average maximum and minimum temperatures of 85·2°F. and 78·5°F, respectively, was as follows : egg, 25 hours ; maggot and pupa, each seven days. The adults could be kept alive when fed on peptone, yeast and sugar under laboratory conditions for about ten days but one male specimen lived as long as five weeks. During the period of six weeks from about the middle of March up to the first week of May in the safflower season the fly completes three generations.

Parasites and predators

The following parasites and predators of the pest were observed :—

1. *Tropideucoila* sp. (probably a new species of the family Cynipidæ). The adults of the parasite were found in small numbers in the field between the end of March and the second week of April. Also a few specimens emerged from the rearing cages in the laboratory. The parasite did not seem to appreciably reduce the population of the pest.

2. *Ormyrus* sp. (Fam. Torymidæ). The chalcidoid wasp was very common in the field and emerged in large numbers in the rearing cages in the laboratory during the second and third weeks of April when the pest was in the second generation. On account of parasitization by this species a significant reduction in the population of the pest was observed in the field and the attack decreased markedly as would be found in the statement of incidence of the pest in the appendix. In association with this parasite, the species *Stenomalus muscarum* (Linn.) (Pteromalidæ) and *Eurytoma* sp. were also found, but the precise role played by them has not been determined. About the same time, the neuropterous predator, *Chrysopa virgestes* was also quite common in the field and its nymphs were found devouring the pest maggots. In the third generation of the pest, extending from the last week of April up to the second week of May, the chalcidoid parasites and the predator were found occurring in very small numbers and the higher incidence of the pest at this time was probably due to this.

Summary

1. *Acanthiophilus helianthi* (Trypetidæ) has been noticed for the first time as a serious pest attacking safflower in India. This is also the first record of this genus and species from this country.

2. The pest was active from March to May and caused serious damage to both early and late sown varieties of safflower, in some of which the infestation of floral buds, was as high as 90 per cent.

3. The fly punctures the flower bud and lays eggs on the inner side of its involucre. The maggots feed upon the florets and even bore into the thalamus. The florets are thus partially or completely destroyed, with the result that the bud does not open. Pupation takes place generally in the bud. The flies emerge through small holes on the surface of the bud. The duration of various stages in April in the laboratory with average maximum and minimum temperatures of 85·2°F. and 78·5°F. was : egg, 25 hours, maggot and pupa, each seven days and adult, 10 days. The fly has three generations during the season (March-May).

4. Two species of hymenopterous parasites on the immature stages of the pest are recorded.

Acknowledgements

The authors are indebted to Mr. H. K. Munro, Entomologist, Department of Agriculture, Union of S. Africa, Pretoria, for the identification of the species and for information about its distribution and host plants outside

India. We are also thankful to the Imperial Economic Botanist for the facilities provided for examining his experimental crop of safflower for the study of the pest. To Mr. Deshpande, M.Sc. (Ag.), Special Research Assistant of the Botanical Section, we are obliged fors upplying some particulars of the varieties.

REFERENCES

Bhatia, H. L. and Singh, M. (1939). *Ind. J. Ent*, **1**, 110-11

Efflatoun, H. C. (1924). *Mem. Soc. Roy. Ent. Egypt* **2**, 117

Meigen, J. W. (1826). *Systematische Beschreibung europaischen Zweiflg ü ligen Insekten*, **5**, 344

Ram, R. (1917). *Proc. Ent. Mtg. Pusa* **2**, 97

Rondani, C. (1871). *Dipterologiae Italicae Prodromi* **7**, 12

Rossi, P. (179). *Fauna Etrusca* **2**, Liburni

Seguy, E. (1930). *Mem. Soc. Sci. Nat. Marocco* **24**, 177

APPENDIX

Statement of the incidence of the fruit fly on various varieties of safflower at Delhi from 28th March to 15th May 1939

Serial No. and features of the type	Number of observations	Total No. of flower buds examined	Average percentage of attack	Range of incidence and remarks
1. (S. L.)	17	449	14·7	5—40 per cent; attack increased after the third week of April.
2. (S. L.)	17	500	12·4	5—45 per cent; attack increased after the third week of April.
3. (S. E.)	17	415	16·6	5—45 per cent; attack increased after the third week of April.
4. (S. E.)	17	478	14·6	5—35 per cent; attack increased after the third week of April.
5. (S. L.)	15	431	16·9	5—45 per cent; attack increased after the third week of April.
6. (S. L.)	15	471	14·8	5—45 per cent; attack increased after the third week of April.

S = Big spines

L = Late variety

E = Early variety

APPENDIX—*contd.*

Serial No. and features of the type	Number of observations.	Total No. of flower buds examined	Average percentage of attack	Range of incidence and remarks
7. (S. L.)	15	437	16·4	5—50 per cent; attack increased after the third week of April.
8. (s$_s$ L.)	16	464	15·5	10—45 per cent; attack high up to the first week and after the third week of April.
9. (s. L.)	16	555	10·5	5—50 per cent; attack increased after the third week of April.
10. (s. L.)	16	471	10·3	5—35 per cent; attack increased after the third week of April.
11. (s. L. F.)	16	376	50·0	10—70 per cent; attack high up to the first week and after the third week of April.
12. (s. L. F.)	16	445	31·2	10—70 per cent; attack high up to the first week and after the third week of April.
13. (s. L. F.)	16	569	19·5	10—65 per cent; attack high up to the first week and after the third week of April.
14. (s. L. F.)	16	424	16·4	5—45 per cent; attack high up to the end of March and after the third week of April.
15. (s. L. F.)	16	490	15·7	5—55 per cent; attack high up to the first week and after the third week of April.
16. (s. L. F.)	16	417	21·1	5—60 per cent; attack increased after the third week of April.
17. (s. L. F.)	16	497	13·8	5—65 per cent; attack increased after the third week of April.
18. (s. L.)	15	319	17·8	5—45 per cent; attack increased after the third week of April.

S = Big spines
s = Small spines
L = Late variety
F = Felted variety

APPENDIX—*contd.*

Serial No. and features of the type	Number of observations	Total No. of flower buds examined	Average percentage of attack	Range of incidence and remarks
19. (s. L.)	15	332	14·7	5—40 per cent; attack increased after the third week of April.
20. (s. L.)	15	360	31·3	5—65 per cent; attack high up to the first and after the second week of April.
21. (s. L.)	15	349	35·5	25—55 per cent; attack high throughout but more so after the third week of April.
22. (s. L.)	15	341	30·7	10—60 per cent; attack high up to the first week and after the third week of April.
23. (s. L.)	15	357	18·2	5—45 per cent; attack increased after the third week of April.
24. (s. L.)	15	332	11·4	5—30 per cent; attack increased after the third week of April.
25. (s. L.)	15	366	17·4	5—40 per cent; attack increased after the third week of April.
26. (S. E.)	15	312	20·8	5—50 per cent; attack increased after the third week of April.

S —Big spines
s —Small spines
L—Late variety
E—Early variety

APPENDIX—*contd.*

Seiral No. and features of the type	Number of observations	Total No. of flower bunds examined	Average percentage of attack	Range of incidence and remarks
27. (S. E.)	15	338	20·1	5—50 per cent; attack increased after the third week of April.
28. (S. E.)	15	378	13·7	5—60 per cent; attack increased after the third week of April.
29. (s. E.)	15	318	30·1	5—60 per cent; attack increased after the third week of April.
30. (s. L.)	15	347	61·9	30—95 per cent; attack high throughout but more in the beginning and towards the end of the season.
31. (s. E.)	14	350	26·8	10—55 per cent; attack increased after the third week of April.
32. (s. E.)	14	329	31·0	10—60 per cent; attack increased after the third week of April.
33. (s. E.)	14	335	31·6	5—75 per cent; attack increased after the third week of April.
34. (s. E.)	14	359	54·5	40—85 per cent; attack high, more in the beginning and towards the end of the season.

S—Big spines
s—Small spines
L—Late variety
E—Early variety

MICRO-BIOLOGICAL DECOMPOSITION OF PLANT MATERIALS

I. CHANGES IN THE CONSTITUENTS OF RICE STRAW (KANAKTARA) PRODUCED BY MICRO-ORGANISMS PRESENT IN SOIL SUSPENSION UNDER AEROBIC, ANAEROBIC AND WATERLOGGED CONDITIONS

BY

S. S. GUHA SIRCAR,

S. C. DE

AND

H. D. BHOWMICK

Department of Chemistry, University of Dacca, Dacca

(Received for publication on 14 December 1938)

(With one text figure)

THE disintegration of various organic residues under the influence of micro-organisms under aerobic, anaerobic and waterlogged conditions have been investigated by various workers. The decomposition of organic matter in well-aerated soils takes place quite rapidly, and Boussingnault [1853] was the first to show that the process was mainly an oxidiation, oxygen being absorbed and an approximately equal volume of carbon dioxide being evolved. On the other hand, it is well known that in badly-aerated waterlogged soils, the destruction of organic matter is slow and incomplete and leads mainly to a reduction to simple organic compounds like methane, hydrogen, organic acids, alcohols, etc. The conditions that control the course of such decompositions have been worked out by the careful and painstaking investigations of Omeliansky [1895, 1897], Hebert [1892], Deherain [1884, 1888, 1902], Hoppe-Seyler [1899], and more recently by Waksman and others [1925-31], Page [1932] and others. The anaerobic type of decomposition has been studied by Deherain [1884, 1888, 1902] and Omeliansky [1895, 1897], who showed that the micro-organisms require nitrogen salts for speedy destruction of organic matter. Waksman and his co-workers [1925-31] and Anderson [1926] confirmed this finding and established a direct relation between the amount of cellulose or hemicellulose decomposed and the nitrogen salt converted into organic form (microbial protein), a 30 : 1 ratio being found to be suitable in a number of cases where the effect of cellulose added to soil was studied. A constant synthesis of proteins and other complex nitrogenous materials by the microbes in soil was noticed even earlier by Deherain [1902] and Lathorp [1912, 1916, 1917].

In the presence of sufficient nitrogen, the decomposition of cellulose and hemicelluloses in the pure state, or in plant residues, by soil organisms takes place rapidly. Waksman and his co-workers [1925-31; 1936] showed clearly that if the nitrogen content of the medium is high, ammonia is set free and if it is low, either the decomposition is slowed down or is only hastened

by adding inorganic nitrogen salts up to a concentration of 1·7 to 1·8 per cent of the material. Acharya [1935] showed that under anaerobic conditions much less nitrogen was required than under aerobic conditions.

It has also been shown by Waksman and others [Waksman and co-workers, 1927-31 ; Deherain, 1902 ; Hebert and Heim, 1911 ; Hebert 1892 ; Hoppe-Seylor, 1899 ; Rege, 1927 ; Bach, 1926 ; Egorov, 1911; Konig, 1926 ; Rose and Lisse, 1917 ; Bray and Andrews, 1924] that of the various components of p'ant organic matter, water-soluble materials are utilized with the greatest speed followed by the hemicelluloses and pentosans, then by cellulose and ultimately by lignin. Some hemicelluloses and pentosans may, however, be re-synthesized by the organisms as well as considerable amounts of proteins. The dark residue or the so-called humus resulting from the decomposition consists, therefore, mainly of modified lignin complexes of plant origin, microbial proteins and hemicelluloses, partly of plant origin and partly synthetic, together with a small amount of fatty and waxy substances, chitinous material, etc.

It has now been established that the course and extent of decomposition of plant residues are influenced by the nature and composition of the material, the degree of aeration, moisture supply, temperature, *p*H of the medium, nature of the micro-organisms attacking the residues, etc. The general stability of lignins explains the lower velocity of decomposition of fibres, like wood and jute, in which the cellulose is associated with lignin, cutin or pectin [Langwell and Lymn, 1923, 1932 ; Fowler and Joshie, 1920 ; Waksman and co-workers, 1927-31]. Isolated lignin has been found to be even more stable and has been regarded as bacteriostatics [Bosuff and Bushwell, 1929, 1930, 1934 ; Phillips and co-workers, 1930 ; Waksman and others, 1925-31 ; 1936.]

Waksman and Tenney [1927-1930] have also shown that a young plant with higher content of water-soluble fraction and nitrogen and lower amounts of lignin and hemicelluloses, etc. decompose much more quickly than mature residues in which the conditions are reversed. The nitrogen content is shown to be a powerful deciding factor. Decomposition of plant materials poor in nitrogen leads to a relative and absolute increase of crude protein content, whereas those rich in nitrogen lose the excess of the element in the form of ammonia.

It has been shown by various workers [Waksman and Tenney, 1929, 1930 ; Waksman, Tenney and Stevens, 1928 and Acharya, 1935] that the rate of decomposition of plant residues as a whole as well as of its various constituents is greatest under aerobic, intermediate under waterlogged (partially aerobic), and least under anaerobic conditions. Again, whereas nitrogen supply is of paramount importance under aerobic conditions, it is of less importance under anaerobic conditions as the requirement of nitrogen by anaerobic organisms is very low. This is well illustrated in Acharya's experiments [1935]. During the decomposition of rice straw under aerobic, anaerobic, and waterlogged conditions, the protein content of the insoluble residue in the first case rises considerably, whereas in the latter two cases loss of this constituent was found to occur. Under mild aeration anaerobic condition of decomposition is stimulated, while strong aeration gives conditions resembling aerobic ; waterlogged condition showing intermediate behaviour in all respects. The nitrogen relationship under the different treatments are of special interest. Similarly

the figures for ' nitrogen factor ' [Rege, 1927] and ' nitrogen equivalent ' [Richards and Norman, 1927] were shown to be the highest under aerobic (0·536 and 1·11, respectively), intermediate under waterlogged (0·395 and 0·961, respectively) and lowest under anaerobic conditions (0·069 and 0·169 respectively). The admission of even a limited amount of air in the anaerobic system at weekly intervals alters the nitrogen relationships, as shown by the synthesis of proteins from ammonia and by the rapid increase in the values for nitrogen factor and nitrogen equivalent.

Various investigations show that the temperature and reaction of the medium exert a profound influence on the rate and extent of decomposition of various organic materials by micro-organisms. Richards and Amoore [1920] at Rothamsted and Bushwell [1930] showed that the optimum conditions for the production of methane are : (1) a temperature between 35° and 40°C., (2) complete exclusion of air, (3) ample water-supply, (4) presence of some available nitrogen, and (5) absence of acidity. Similar results were also found by Acharya [1935] for anaerobic fermentation of rice straw. As the anaerobic decomposition is accompanied by the formation of various organic acids with the consequent lowering of *p*H of the medium, the fermentation process comes practically to a standstill as the *p*H falls to about 4·8, unless proper neutralizing agents are employed. Ammonium carbonate in sufficient amount was the most suitable neutralizing agent, while calcium carbonate, even in sufficient excess, was unable to retard the fall in the *p*H of the medium. When sodium nitrate was employed, there was no fall in *p*H but a gradual rise, accompanied by the maximum destruction of organic matter as a whole as well as of its various constituents. The reaction appeared to proceed in two stages : (1) denitrification and oxidation of organic matter, and (2) the development of alkalinity owing to the formation of alkali carbonates. This system resembled more the aerobic than the anaerobic system.

While the control of acidity is of great importance in the case of anaerobic fermentation, it is less so in the case of aerobic decomposition. In the latter case the fermentation is carried out by a larger variety of micro-organisms including bacteria, fungi and actinomycetes and thus the decomposition can proceed in neutral, slightly acid and slightly alkaline medium. Fungi, which are most important in the disposal of cellulosic materials under aerobic conditions are most active in slightly acid reaction. Too high an acidity or too high an alkalinity inhibit the action of both fungi and bacteria. Acharya [1935] found that there was no fall in *p*H of the medium, but a small rise, in the case of aerobic decomposition of rice straw, because the organic matter is converted completely to carbon dioxide and water without the formation of intermediate organic acids.

The aim of the present paper was to study the course of decomposition of two samples of rice straw at different stages of growth, under aerobic, anaerobic and waterlogged conditions with different neutrient solutions and under different *p*H of the media by following the changes in the amount of total organic matter as a whole as well as of its more important constituents with the progress of decomposition. At the same time attention was given to the changes in the *p*H of the media employed and to the influence of neutralizing

agents in successfully preventing the development of acidity. Stress was laid on the composition of the ultimate insoluble residue which would be expected to approach the composition of humus provided the decomposition went fast enough and far enough.

Experimental

Composition of plant materials used in the present investigation

The rice plants used in the present investigation were of two different ages, the rice straw No. 1 being younger, while the rice straw No. 2 was fully mature. Their proximate chemical compositions are given in Table I.

Table I

Proximate chemical composition of rice straw (Kanak Tara) used for decomposition studies

Chemical constituents	Rice straw No. 1 (young)		Rice straw No. 2 (mature)	
	100 gm. of original plant material	On per cent basis of dry material	100 gm. of original plant material	On per cent basis of dry material
Moisture[1]	12·99	..	12·45	..
Dry matter	87·01	..	87·55	..
Ash[2]	13·12	15·08	10·15	11·60
Water-soluble fraction	16·46	18·92	12·46	14·23
Fats and waxes[3]	1·32	1·52	0·74	0·85
Total pentosans[4]	18·86	21·68	22·31	25·49
Crude cellulose[5]	37·90	43·56	43·35	49·52
Ash in above	1·30	1·49	0·23	0·26
Pentosans in above	7·16	8·23	11·22	12·81
Cellulose	29·44	33·84	31·90	36·44
Crude lignin[6]	20·68	23·78	22·83	26·08
Ash in lignin	6·38	7·33	5·10	5·83
Lignin	14·30	16·45	17·73	21·15
Total nitrogen[7]	1·80	2·07	0·53	0·61
Crude protein[8]	6·21	7·14	1·83	2·09

[1] Moisture—estimated at 105°C.

[2] Ash was found to contain Na, K, Ca, Mg, Fe, Al, Mn, SiO_2 and sulphate and phosphate, SiO_2 constituting the major part of the mineral constituents.

[3] Fats and waxes—estimated by extraction with alcohol-benzene (1 : 1).

[4] Pentosans—the standard Phloroglucide method as recommended by A. O. A. C. [1935] was employed.

[5] Cellulose—the method of Norman and Jenkins [1935] was employed. The ash and pentosan content were subtracted to get the value for true cellulose.

[6] Lignin—the method due to Ost and Wilkening [1910] involving the use of 72 per cent H_2SO_4 gives results which are more consistent ; a modification of it put forward by Schwalbe [1925] was employed, the material being previously freed from fats and waxes and hemicelluloses (by extraction with hot 2 per cent HCl).

[7] Total nitrogen—estimated by modified Kjeldahl method using Na_2SO_4, $Na_2S_2O_3$, salicylic acid and $CuSO_4$ in addition to conc. H_2SO_4.

[8] Crude protein—the material was extracted by boiling water and analysed for nitrogen. The figure for nitrogen multiplied by 6·25 was expressed as crude protein.

The above data show that in the maturer plant, there are lower amounts of mineral matter (ash), fats and waxes, crude protein and water-soluble fraction, and higher amounts of cellulose, hemicelluloses and lignin. The water-soluble fraction on analysis was found to contain amino-acids and reducing sugars, the amount being greater in rice straw No. 1 than in rice straw No. 2. Similar results were obtained by Hunt [1889] and Waksman and Tenney [1927].

Decomposition experiments

The plant materials were cut into small pieces and then macerated in a pulverizing machine and 20 gm. of each variety were placed in a series of glass bottles. Mineral nutrients and soil inoculant* together with distilled water were added as described below and the contents well mixed so that the straw : water ratio was 1 : 10.

The aerobic decomposition was carried out in a series of glass bottles fitted with airtight corks through which two glass tubes (one reaching the bottom of the vessel and the other about two inches above the surface of the material) were inserted. Air passed through a wash-bottle containing distilled water was bubbled through the mass for about half an hour daily. It was observed that abundant fungal growth accompanied the process of decomposition under aerobic conditions. The mass of the residual matter became darker and darker with the progress of decomposition.

The anaerobic decomposition was carried in a number of 'reagent bottles' of about 300 c. c. capacity, fitted with rubber corks, exit tubes and pressure tubes about three inches long. The anaerobic condition was secured by a technique which would be clear from the diagram. The bottle (B) was connected as in the Fig. 1. The stop cock (*a*) was closed, (*b*) and (*c*) opened, and the enclosed air was removed by suction with a vacuum pump. The stop cock (*b*) was then closed and (*a*) opened and a measured volume of the solution (200 c.c.) was added to the enclosed straw and then (*a*) and (*c*) were closed. The end of the rubber tube was closed by a piece of glass tubing sealed at both ends. Acharya [1935] first filled the bottles with reaction mixture and then removed the air by suction. The method used in the present paper is easier and more convenient and involves no frothing up of the mixture during evacuation. The corks and rubber joints were coated with paraffin wax. The bottles were kept in a glass chamber at the laboratory temperature. The gases formed during fermentation were removed from time to time from the bottles by means of a Hempel gas burette, care being taken to avoid the entry of air. Qualitative analysis showed that the gases consisted mainly of carbon dioxide, methane, hydrogen and nitrogen depending on the nature of the mineral nutrients present in the medium.

The process of decomposition under waterlogged conditions was carried out in wide-mouthed bottles and the experiments were so arranged that the materials undergoing decomposition were completely covered with about two inches of water.

*Prepared by thoroughly agitating some well-manured garden soil with water, allowing the coarse particles to settle and centrifuging the supernatant liquid.

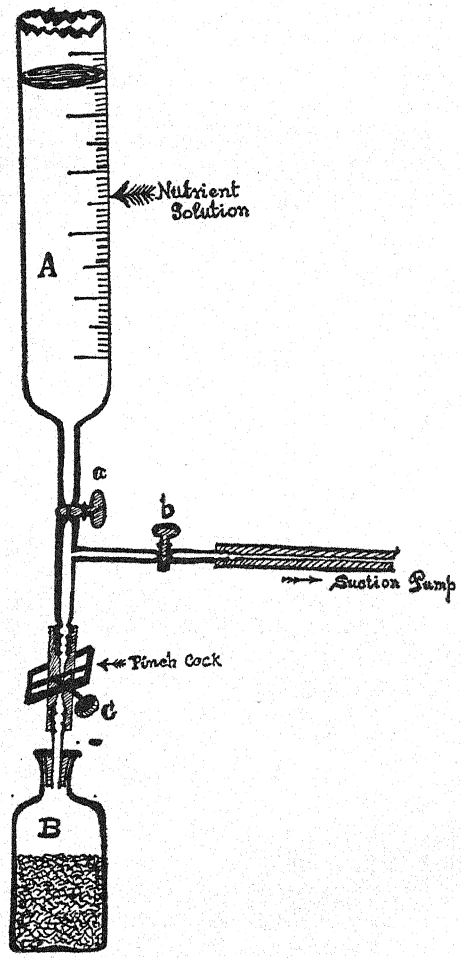


FIG. 1. Apparatus for obtaining anaerobic conditions

From time to time the mass was shaken well and in the case of aerobic and waterlogged fermentations a little fresh water was added to each bottle to replace the loss due to evaporation. It was noticed that even under waterlogged conditions there was a tendency for the materials to form a fungal growth on the surface of the water unless the mass was regularly stirred up. Under these conditions the anaerobic bacteria were no doubt mostly concerned in the decomposition in the lower part of the material, whereas the upper part in contact with the air was subjected to the action of various aerobic organisms including bacteria, fungi and actinomycetes. The waterlogged system should therefore occupy an intermediate position between aerobic and anaerobic systems.

After specified intervals the bottles were opened, the contents were filtered through a Buchner funnel and then roughly washed with distilled water. In the case of materials receiving calcium carbonate, the residue was treated

with excess of dilute hydrochloric acid (strength about 0·5 per cent) and then thoroughly washed with water immediately after the carbonate was brought into solution. It was found in a preliminary experiment that by this treatment, the pentosans and hexosans are not affected as the reaction was completed within four to five minutes. The residue was dried and aliquot portions were subjected to detailed chemical analysis (as shown in individual tables).

The experiments were conducted with different nutrient solutions (added per 20 gm. of rice straw) having the following compositions :—

1. With distilled water—
   Soil solution 10 c.c.
   Distilled water 190 c.c.
2. With magnesium sulphate and sodium phosphate—
   Sodium phosphate solution 10 c.c. (containing 0·25 gm.).
   Magnesium sulphate solution 10 c.c. (containing 0·05 gm.).
   Soil solution 10 c.c.
   Distilled water 170 c.c.
3. With calcium carbonate alone—
   Calcium carbonate 8 gm.
   Soil solution 10 c.c.
   Distilled water 190 c.c.
4. With calcium carbonate and ammonium carbonate—
   Calcium carbonate 5 gm.
   Ammonium carbonate solution 10 c.c. (containing 0·6857 gm.)
   Soil solution 10 c.c.
   Distilled water 180 c.c.
5. With ammonium carbonate alone—
   Ammonium carbonate solution 10 c.c. (containing 1·3714 gm.)
   Soil solution 10 c.c.
   Distilled water 180 c.c.
6. With sodium nitrate—
   Sodium nitrate solution 10 c.c. (containing 2·4288 gm.)
   Soil solution 10 c.c.
   Distilled water 180 c.c.

The following experiments were performed with rice straw No. 1 and rice straw No. 2, under aerobic, anaerobic and waterlogged conditions and the tables in which the results of the analysis are shown, are mentioned below :—

Aerobic condition

Table II.—Decomposition of rice straw No. 1 with distilled water only
Table III.—Decomposition of rice straw No. 1 with magnesium sulphate and sodium phosphate
Table IV.—Decomposition of rice straw No. 1 with calcium carbonate and ammonium carbonate
Table V.—Decomposition of rice straw No. 1 with ammonium carbonate alone
Table VI.—Decomposition of rice straw No. 1 with sodium nitrate
Table VII.—Decomposition of rice straw No. 2 with distilled water only

Table VIII.—Decomposition of rice straw No. 2 with calcium carbonate and ammonium carbonate

Anaerobic condition

Table IX.—Decomposition of rice straw No. 1 with distilled water only
Table X.—Decomposition of rice straw No. 2 with distilled water only
Table XI.—Decomposition of rice straw No. 2 with sodium phosphate and magnesium sulphate
Table XII.—Decomposition of rice straw No. 2 with calcium carbonate alone
Table XIII.—Decomposition of rice straw No. 1 with calcium carbonate and ammonium carbonate
Table XIV.—Decomposition of rice straw No. 2 with calcium carbonate and ammonium carbonate
Table XV.—Decomposition of rice straw No. 2 with ammonium carbonate
Table XVI.—Decomposition of rice straw No. 2 with sodium nitrate

Waterlogged condition

Table XVII.—Decomposition of rice straw No. 1 with distilled water only
Table XVIII.—Decomposition of rice straw No. 2 with distilled water only
Table XIX.—Decomposition of rice straw No. 1 with calcium carbonate and ammonium carbonate
Table XX.—Decomposition of rice straw No. 2 with calcium carbonate and ammonium carbonate

Discussion of results obtained

A study of Tables II—VIII shows that the *p*H of the media under aerobic conditions fell slightly during the early periods of decomposition and then gradually rose till a value slightly higher than the original was attained. This may be due to accumulation of organic acids at the early stages which, however, were completely oxidized to carbon dioxide and water with the progress of decomposition. The slight rise of *p*H of the media may be due to the formation of ammonia as a result of protein decomposition. In the case of Table VI, there was no fall in *p*H of the medium, but a gradual rise probably due to denitrification and formation of alkali carbonates even under aerobic conditions. This result is not in a line with the observations of a number of other observers who are of opinion that denitrification is not possible under ideal aerobic conditions. The difference may be due to the fact that air supply was not as complete in the depths of the medium as on the surface except for half an hour daily.

TABLE II

Decomposition of various constituents of rice straw No. 1 with distilled water only under aerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition											
		1 month		2 months		3 months		4 months		5 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·01	55·34	63·60	50·19	57·67	42·84	49·23	39·55	45·45	36·47	41·92	32·99	37·92
Ash	13·12	6·52	...	6·34	...	5·86	...	5·82	...	5·65	...	5·14	...
Fats and waxes	1·32	0·78	59·09	0·63	47·72	0·52	39·40	0·43	32·58	0·42	31·81	0·40	30·31
Total pentosans	18·86	11·31	59·96	10·12	53·65	8·23	43·63	6·99	37·06	6·18	32·76	5·86	31·07
Crude cellulose	37·90	23·88	...	20·19	...	16·57	...	14·41	...	13·68	...	12·28	...
Ash in above	1·30	1·22	...	0·94	...	0·73	...	0·67	...	0·56	...	0·51	...
Pentosans in above	7·16	4·80	...	4·32	...	3·80	...	2·61	...	2·15	...	1·94	...
Cellulose	29·44	17·86	60·67	14·93	50·72	12·04	40·90	11·13	37·81	10·97	37·27	9·83	33·39
Crude lignin	20·68	20·18	...	19·01	...	17·63	...	16·88	...	15·12	...	14·05	...
Ash in above	6·38	6·25	...	5·18	...	4·48	...	4·32	...	4·21	...	4·21	...
Lignin	14·30	13·93	97·43	13·83	96·74	13·15	91·96	12·56	87·82	10·91	76·30	9·84	68·82
Crude protein	6·21	5·82	93·71	5·23	84·22	4·56	73·41	4·35	70·04	4·06	65·37	3·56	57·32
*p*H	6·88	6·21		6·21		6·9		7·15		7·20		7·20	
Per cent of protein-N_2 in the residue	0·91	1·68		1·67		1·70		1·76		1·78		1·73	

TABLE III

Decomposition of various constituents of rice straw No. 1 with magnesium sulphate and sodium phosphate under aerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition											
		1 month		2 months		3 months		4 months		5 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·01	51·92	59·67	45·12	51·87	39·98	45·96	35·35	40·63	31·28	35·96	27·95	32·13
Ash	13·12	6·52	...	5·82	...	5·38	...	4·69	...	4·24	...	4·12	...
Fats and waxes	1·32	0·59	44·70	0·55	41·67	0·48	36·36	0·45	34·09	0·41	31·06	0·42	31·81
Total pentosans	18·86	10·65	56·45	9·06	48·03	8·39	44·48	6·45	34·20	5·37	28·47	4·87	25·81
Crude cellulose	37·90	21·93	...	18·49	...	14·62	...	12·19	...	10·40	...	9·06	...
Ash in above	1·30	1·01	...	0·82	...	0·65	...	0·53	...	0·49	...	0·46	...
Pentosans in above	7·16	4·82	...	4·21	...	3·32	...	2·13	...	1·67	...	1·52	...
Cellulose	29·44	16·10	54·69	13·46	45·73	10·65	36·17	9·53	32·37	8·24	27·99	7·08	24·05
Crude lignin	20·68	19·23	...	18·46	...	16·48	...	16·10	...	14·73	...	13·19	...
Ash in above	6·38	5·43	...	5·40	...	4·98	...	4·28	...	3·80	...	3·81	...
Lignin	14·30	13·80	96·51	13·06	91·33	11·50	80·42	11·82	82·66	10·93	76·43	9·38	65·60
Crude protein	6·21	5·93	95·50	4·89	78·74	4·41	71·01	3·86	62·16	3·68	59·26	3·37	54·26
*p*H	8·05	7·77		8·15		8·20		8·47		8·59		8·59	
Per cent of protein-N_2 in the residue	0·91	1·83		1·73		1·76		1·75		1·88		1·93	

TABLE IV

Decomposition of various constituents of rice straw No. 1 with calcium carbonate and ammonium carbonate under aerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition: 1 month		2 months		3 months		4 months		5 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·01	46·55	53·50	38·98	44·80	33·44	38·43	28·19	32·41	24·66	28·35	22·23	25·56
Ash	13·12	5·41	...	3·71	...	2·74	...	2·61	...	2·18	...	2·14	...
Fats and waxes	1·32	0·56	42·46	0·43	32·58	0·39	29·54	0·32	24·24	0·26	19·70	0·24	18·18
Total pentosans	18·86	10·12	53·65	8·53	45·22	7·28	38·59	6·99	37·06	5·61	29·75	4·91	26·03
Crude cellulose	37·90	19·92	...	15·98	...	13·15	...	11·58	...	10·11	...	8·50	...
Ash in above	1·30	0·80	...	0·62	...	0·50	...	0·48	...	0·42	...	0·40	...
Pentosans in above	7·16	4·30	...	3·22	...	2·36	...	2·12	...	1·80	...	1·51	...
Cellulose	29·44	14·82	50·35	12·14	41·24	10·29	34·95	8·98	30·51	7·89	26·80	6·59	22·39
Crude lignin	20·68	17·92	...	15·56	...	13·36	...	10·43	...	9·68	...	8·40	...
Ash in above	6·38	4·64	...	3·45	...	2·54	...	2·14	...	2·00	...	1·97	...
Lignin	14·30	13·28	92·87	12·11	84·68	10·82	75·66	8·29	57·98	7·68	53·71	6·43	44·96
Crude protein	6·21	4·94	79·54	4·33	69·72	3·80	61·19	3·38	54·43	2·73	43·96	2·31	37·19
*p*H	8·55	8·41		7·9		8·17		8·65		8·85		8·88	
Per cent of protein-N_2 in the residue	0·91	1·70		1·78		1·82		1·92		1·77		1·66	

TABLE V

Decomposition of various constituents of rice straw No. 1 with ammonium carbonate under aerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition											
		1 month		2 months		3 months		4 months		5 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·01	44·71	51·40	36·67	42·13	30·53	35·10	25·44	29·24	22·92	26·34	20·89	24·02
Ash	13·12	5·30	...	3·64	...	2·52	...	2·45	...	2·17	...	2·14	...
Fats and waxes	1·32	0·53	40·15	0·45	34·09	0·39	29·54	0·35	26·52	0·28	21·21	0·23	17·42
Total pentosans	18·86	9·23	48·94	8·07	42·79	6·86	36·37	5·83	30·91	5·03	26·67	4·38	23·22
Crude cellulose	37·90	17·69	...	15·38	...	11·81	...	10·44	...	9·31	...	8·05	...
Ash in above	1·30	0·75	...	0·64	...	0·41	...	0·32	...	0·30	...	0·28	...
Pentosans in above	7·16	3·32	...	3·03	...	2·13	...	1·82	...	1·75	...	1·49	...
Cellulose	29·44	13·62	46·27	11·71	39·78	9·27	31·49	8·30	28·19	7·26	24·66	6·28	21·33
Crude lignin	20·68	16·98	...	14·08	...	12·46	...	9·53	...	9·34	...	8·07	...
Ash in above	6·38	4·52	...	3·52	...	2·45	...	2·24	...	1·86	...	1·75	...
Lignin	14·30	12·46	87·14	10·56	73·84	10·01	70·00	7·29	50·98	7·48	52·31	6·32	44·20
Crude protein	6·21	4·73	76·17	4·12	66·34	3·35	53·94	3·04	48·96	2·61	42·03	2·53	40·74
*p*H	8·69	8·44		8·46		8·51		8·85		8·85		8·91	
Per cent of protein-N_2 in the residue	0·91	1·69		1·80		1·76		1·91		1·82		1·94	

TABLE VI

Decomposition of various constituents of rice straw No. 1 with sodium nitrate under aerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition											
		1 month		2 months		3 months		4 months		5 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·01	41·23	47·40	33·82	38·88	26·45	30·40	21·96	25·24	20·51	23·58	19·68	22·62
Ash	13·12	5·28	...	3·56	...	2·53	...	2·42	...	2·01	...	1·89	...
Fats and waxes	1·32	0·44	33·34	0·41	31·06	0·39	29·54	0·37	28·03	0·25	18·93	0·22	16·66
Total pentosans	18·86	7·69	40·77	7·10	37·64	5·20	27·57	4·46	23·64	4·19	22·21	3·87	20·51
Crude cellulose	37·90	16·60	...	12·91	...	9·93	...	8·98	...	8·14	...	7·78	...
Ash in above	1·30	0·65	...	0·51	...	0·49	...	0·41	...	0·32	...	0·28	...
Pentosans in above	7·16	3·14	...	2·32	...	1·98	...	1·72	...	1·51	...	1·48	...
Cellulose	29·44	12·81	43·51	9·98	33·90	7·46	25·34	6·85	23·27	6·31	21·43	6·02	20·45
Crude lignin	20·68	15·95	...	12·80	...	11·25	...	8·56	...	8·40	...	7·90	...
Ash in above	6·38	3·74	...	2·50	...	2·23	...	2·22	...	2·03	...	1·78	...
Lignin	14·30	12·21	85·39	10·30	72·03	9·02	63·08	6·34	44·34	6·37	44·54	6·12	42·81
Crude protein	6·21	4·52	72·78	3·86	62·16	3·18	51·21	2·65	42·67	2·48	39·94	2·40	38·81
*p*H	6·88	8·72		9·35		9·65		9·80		9·92		9·93	
Per cent of protein-N_2 in the residue	0·91	1·75		1·83		1·92		1·93		1·94		1·95	

TABLE VII

Decomposition of rice straw No. 2 with distilled water only under aerobic conditions

Chemical constituents	100 gm. original straw	Materials left after months of decomposition					
		1 month		3 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	65·75	75·11	55·08	62·92	45·28	51·72
Ash	10·15	5·62	..	5·58	..	5·27	..
Fats and waxes	0·74	0·38	51·35	0·35	47·30	0·27	36·49
Total pentosans	22·31	15·12	67·77	11·86	53·16	10·15	45·49
Crude cellulose	43·35	33·12	..	25·72	..	19·22	..
Ash in above	0·23	0·24	..	0·19	..	0·16	..
Pentosans in above	11·22	8·13	..	4·52	..	3·41	..
Cellulose	31·90	24·75	77·59	21·01	65·86	15·65	49·05
Crude lignin	22·83	19·93	..	15·90	..	13·67	..
Ash in above	5·10	3·08	..	2·93	..	2·75	..
Lignin	17·73	16·85	95·04	12·97	73·16	10·92	61·59
Crude protein	1·83	2·58	140·98	2·92	159·56	3·21	175·41
*p*H	6·88	6·01		6·60		6·70	
Per cent of protein-N_2 in the residue	0·33	0·63		0·85		1·13	

TABLE VIII

Decomposition of various constituents of rice straw No. 2 with calcium carbonate and ammonium carbonate under aerobic conditions

Chemical constituents	100 gm. original straw	Materials left after months of decomposition					
		1 month		3 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	61·77	70·57	51·88	59·27	43·11	49·25
Ash	10·15	5·55	..	5·01	..	4·85	..
Fats and waxes	0·74	0·31	41·90	0·27	36·50	0·21	28·38
Total pentosans	22·31	14·63	65·58	11·28	50·56	9·54	42·76
Crude cellulose	43·35	30·84	..	23·08	..	16·95	..
Ash in above	0·23	0·23	..	0·19	..	0·17	..
Pentosans in above	11·22	7·51	..	3·95	..	2·58	..
Cellulose	31·90	23·10	72·41	18·94	59·37	14·20	44·51
Crude lignin	22·83	18·42	..	15·74	..	13·57	..
Ash in above	5·10	3·13	..	2·84	..	2·75	..
Lignin	17·73	15·29	86·24	12·90	72·76	10·72	60·46
Crude protein	1·83	2·64	144·20	3·09	168·90	3·43	187·40
*p*H	8·55	7·84		8·18		8·80	
Per cent of protein N in the residue	0·33	0·68		0·95		1·27	

TABLE IX

Decomposition of various constituents of rice straw No. I with distilled water only under anaerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition					
		1 month		3 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·01	60·82	69·90	54·98	63·19	50·27	57·77
Ash	13·12	6·85	..	6·12	..	5·73	..
Fats and waxes	1·32	0·89	67·42	0·81	61·36	0·75	56·82
Total pentosans	18·86	14·95	79·26	12·48	66·17	10·36	54·93
Crude cellulose	37·90	26·14	..	24·80	..	22·40	..
Ash in above	1·30	0·85	..	0·75	..	0·63	..
Pentosans in above	7·16	5·13	..	4·21	..	3·65	..
Cellulose	29·44	21·16	71·87	19·84	67·39	18·12	61·55
Crude lignin	20·68	18·92	..	17·54	..	16·17	..
Ash in above	6·38	4·64	..	3·62	..	2·59	..
Lignin	14·30	14·28	99·86	13·92	97·41	13·58	94·96
Crude protein	6·21	2·67	42·99	1·75	28·18	1·42	22·87
*p*H	6·88	4·91		4·40		4·20	
Per cent of protein N in the residue	0·91	0·70		0·51		0·45	

TABLE X

Decomposition of various constituents of rice straw No. 2 with distilled water only under anaerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition							
		1 month		2 months		3 months		4 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	75·98	86·78	69·95	79·91	67·77	77·41	67·42	77·07
Ash	10·15	7·41	..	5·91	..	5·82	..	5·82	..
Fats and waxes	0·74	0·61	82·43	0·58	78·38	0·48	64·86	0·46	62·16
Total pentosans	22·31	19·84	88·92	17·85	80·00	16·49	73·91	16·25	72·84
Crude cellulose	43·35	38·28	..	35·35	..	34·96	..	34·93	..
Ash in above	0·23	0·22	..	0·21	..	0·22	..	0·22	..
Pentosans in above	11·22	9·71	..	8·98	..	8·75	..	8·73	..
Cellulose	31·90	28·35	88·87	26·16	82·01	25·99	81·48	25·98	81·45
Crude lignin	22·83	22·24	..	22·15	..	22·11	..	21·71	..
Ash in above	5·10	5·01	..	5·20	..	5·20	..	5·12	..
Lignin	17·73	17·23	97·18	16·95	95·60	16·91	95·31	16·59	93·57
Crude protein	1·83	1·91	104·30	1·87	102·20	1·89	103·30	1·94	106·00
*p*H	6·88	5·27		4·82		4·61		4·53	
Per cent of protein N in the residue	0·33	0·40		0·43		0·45		0·46	

TABLE XI

Decomposition of various constituents of rice straw No. 2 with magnesium sulphate and sodium phosphate under anaerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition									
		1 month		2 months		3 months		4 months		5 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	73·68	84·18	70·59	80·65	68·33	78·05	65·92	75·30	65·87	75·25
Ash	10·15	6·74	...	6·24	...	6·22	...	6·22	...	6·25	...
Fats and waxes	0·74	0·58	78·38	0·55	74·33	0·49	66·22	0·48	64·86	0·46	62·18
Total pentosans	22·31	19·68	88·20	18·83	84·41	17·89	80·19	17·55	79·11	17·59	78·83
Crude cellulose	43·35	36·67	...	33·95	...	33·23	...	32·30	...	30·88	...
Ash in above	0·23	0·22	...	0·20	...	0·21	...	0·19	...	0·19	...
Pentosans in above	11·22	9·65	...	8·72	...	8·68	...	8·46	...	8·42	...
Cellulose	31·90	26·80	84·01	25·03	78·45	24·34	76·30	23·65	74·13	22·27	69·82
Crude lignin	22·83	22·02	...	21·84	...	21·50	...	21·44	...	21·46	...
Ash in above	5·10	4·74	...	4·72	...	4·61	...	4·70	...	4·68	...
Lignin	17·73	17·28	97·45	17·12	96·56	16·89	95·26	16·74	94·41	16·78	94·64
Crude protein	1·83	1·92	104·90	1·91	104·36	1·89	103·30	1·83	100·00	1·82	99·45
H	5·05	6·82		5·01		4·89		4·56		4·32	
Per cent of protein N in the residue	0·33	0·42		0·43		0·44		0·44		0·44	

TABLE XII

Decomposition of various constituents of rice straw No. 2 with calcium carbonate alone under anaerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition											
		1 month		2 months		3 months		4 months		5 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	71·68	81·87	66·51	75·97	63·83	72·91	62·76	71·68	61·84	70·63	61·49	70·23
Ash	10·15	7·12	...	6·85	...	6·52	...	6·49	...	6·35	...	6·34	...
Fats and waxes	0·74	0·69	93·24	0·66	89·19	0·58	78·38	0·56	75·68	0·58	78·38	0·55	74·32
Total pentosans	22·31	18·15	81·35	16·93	75·89	16·12	72·25	15·85	71·04	15·64	70·10	15·62	70·01
Crude cellulose	43·35	36·89	...	34·11	...	33·27	...	32·92	...	32·87	...	32·63	...
Ash in above	0·23	0·21	...	0·19	...	0·20	...	0·18	...	0·19	...	0·18	...
Pentosans in above	11·22	9·85	...	9·65	...	9·42	...	9·51	...	9·53	...	9·48	...
Cellulose	31·90	26·83	84·10	24·27	76·08	23·65	74·13	23·23	72·82	23·15	72·57	22·97	72·00
Crude lignin	22·83	21·73	...	20·40	...	19·92	...	19·56	...	19·00	...	18·89	...
Ash in above	5·10	5·10	...	5·05	...	5·10	...	5·06	...	4·98	...	4·89	...
Lignin	17·73	16·63	93·80	15·35	86·57	14·82	83·56	14·50	81·78	14·02	79·08	14·00	78·96
Crude protein.	1·83	1·95	106·50	1·88	102·80	1·93	105·40	1·89	103·30	1·82	99·45	1·80	98·35
*p*H	6·88	5·43		5·28		5·01		4·62		4·60		4·60	
Per cent of protein N in the residue	0·33	0·44		0·45		0·48		0·48		0·47		0·47	

TABLE XIII

Decomposition of various constituents of rice straw No. 1 with calcium carbonate and ammonium carbonate under anaerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition					
		1 month		3 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·01	54·86	63·08	47·27	54·33	41·48	47·67
Ash	13·12	5·42	..	4·15	..	2·93	..
Fats and waxes	1·32	0·76	57·57	0·63	47·72	0·47	35·60
Total pentosans	18·86	13·64	72·31	11·42	60·54	9·52	50·47
Crude cellulose	37·90	22·85	..	20·16	..	17·04	..
Ash in above	1·30	0·84	..	0·72	..	0·51	..
Pentosans in above	7·16	4·72	..	3·82	..	2·46	..
Cellulose	29·44	17·29	58·72	15·62	53·07	14·07	47·79
Crude lignin	20·68	18·92	..	17·34	..	15·79	..
Ash in above	6·38	4·65	..	3·59	..	2·46	..
Lignin	14·30	14·27	99·79	13·75	96·15	13·33	93·24
Crude protein	6·21	1·83	29·47	1·38	22·22	1·13	18·20
*p*H	8·55	5·70		5·23		4·67	
Per cent of protein N in the residue	0·91	0·53		0·47		0·44	

TABLE XIV

Decomposition of various constituents of rice straw No. 2 with calcium carbonate and ammonium carbonate under anaerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition											
		1 month		2 months		3 months		4 months		5 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	67·58	77·20	65·15	74·42	64·22	73·33	62·01	70·84	60·48	69·08	60·17	68·74
Ash	10·15	6·98	...	6·82	...	6·75	...	6·48	...	6·22	...	6·18	...
Fats and waxes	0·74	0·65	87·84	0·61	82·43	0·59	79·75	0·58	78·38	0·56	75·68	0·54	72·98
Total pentosans	22·31	17·82	79·87	16·01	71·76	15·79	70·78	15·41	69·07	15·10	67·66	14·98	67·14
Crude cellulose	43·35	34·47	...	33·85	...	32·86	...	31·49	...	30·86	...	30·80	...
Ash in above	0·23	0·21	...	0·22	...	0·20	...	0·18	...	0·19	...	0·18	...
Pentosans in above	11·22	9·72	...	9·62	...	9·12	...	8·85	...	8·69	...	8·74	...
Cellulose	31·90	24·54	76·93	24·01	75·26	23·54	73·79	22·46	70·41	21·98	68·90	21·88	68·58
Crude lignin	22·80	20·25	...	20·41	...	19·67	...	19·26	...	18·97	...	18·92	...
Ash in above	5·10	4·95	...	5·01	...	4·85	...	4·62	...	4·59	...	4·53	...
Lignin	17·73	15·30	86·30	15·40	86·86	14·82	83·60	14·64	82·58	14·38	81·12	14·39	81·17
Crude protein	1·83	1·88	102·80	1·87	102·20	1·92	104·90	1·82	99·45	1·73	94·52	1·72	93·97
*p*H	8·55	5·61		5·32		5·13		5·00		4·82		4·80	
Per cent of protein N in the residue	0·33	0·45		0·46		0·48		0·47		0·46		0·46	

TABLE XV

Decomposition of various constituents of rice straw No. 2 with ammonium carbonate under anaerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition											
		1 month		2 months		3 months		4 months		5 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	66·09	75·50	62·54	71·45	60·55	69·18	57·70	65·92	56·83	64·91	55·48	63·37
Ash	10·15	6·42	...	6·38	...	6·38	...	6·12	...	6·05	...	5·07	...
Fats and waxes	0·74	0·49	66·22	0·48	64·86	0·49	66·22	0·46	62·18	0·44	59·48	0·43	58·12
Total pentosans	22·31	17·76	79·62	15·73	70·51	15·21	68·17	14·70	65·89	14·72	65·98	14·68	65·80
Crude cellulose	43·35	33·87	...	32·49	...	30·72	...	28·26	...	27·79	...	27·45	...
Ash in above	0·23	0·22	...	0·20	...	0·22	...	0·21	...	0·19	...	0·19	...
Pentosans in above	11·22	9·23	...	8·61	...	7·93	...	7·22	...	6·82	...	6·73	...
Cellulose	31·90	24·42	76·56	23·68	74·23	22·52	70·60	20·83	65·28	20·78	65·13	20·53	64·36
Crude lignin	22·83	19·84	...	18·56	...	18·09	...	18·15	...	17·66	...	17·45	...
Ash in above	5·10	5·01	...	4·99	...	4·68	...	4·63	...	4·44	...	4·42	...
Lignin	17·73	14·83	83·66	13·57	76·54	13·41	75·63	13·52	76·26	13·22	74·57	13·03	73·48
Crude protein	1·83	1·86	101·60	1·82	99·45	1·73	94·52	1·73	94·52	1·70	92·87	1·67	91·24
pH	8·69	6·73		6·43		6·01		5·60		5·42		5·29	
Per cent of protein N in the dry matter	0·33	0·45		0·47		0·46		0·48		0·48		0·48	

TABLE XVI

Decomposition of various constituents of rice straw No. 2 with sodium nitrate under anaerobic conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition											
		1 month		2 months		3 months		4 months		5 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	64·03	73·14	56·62	64·69	49·70	56·78	43·71	49·94	42·06	48·04	39·98	45·67
Ash	10·15	6·24	...	5·79	...	4·72	...	4·55	...	4·21	...	3·95	...
Fats and waxes	0·74	0·47	63·51	0·43	58·11	0·45	60·81	0·38	51·36	0·36	48·65	0·34	45·94
Total pentosans	22·31	17·22	77·18	15·03	67·38	13·09	58·66	11·27	50·52	11·32	50·75	10·77	48·27
Crude cellulose	43·35	32·01	...	25·79	...	21·69	...	19·8	...	18·56	...	17·41	...
Ash in above	0·23	0·23	...	0·21	...	0·21	...	0·19	...	0·17	...	0·18	...
Pentosans in above	11·22	8·01	...	6·35	...	5·12	...	4·52	...	4·11	...	3·88	...
Cellulose	31·90	23·77	74·50	19·23	60·29	16·36	51·29	15·09	47·28	14·28	44·77	13·35	41·85
Crude lignin	22·83	19·00	...	18·32	...	16·38	...	14·13	...	13·94	...	13·60	...
Ash in above	5·10	4·91	...	4·91	...	3·98	...	3·92	...	3·89	...	3·75	...
Lignin	17·73	14·09	79·45	13·41	75·63	12·40	69·93	10·21	57·58	10·05	56·67	9·85	55·55
Crude protein	1·83	1·92	104·90	1·71	93·44	1·56	85·23	1·37	74·85	1·29	70·49	1·20	65·57
*p*H	6·88	7·43		7·81		8·12		8·54		8·01		7·80	
Per cent of protein N in the residue	0·33	0·48		0·48		0·50		0·50		0·49		0·48	

TABLE XVII

Decomposition of various constituents of rice straw No. 1 with distilled water only under waterlogged conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition					
		1 month		3 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·01	56·93	65·43	48·24	55·46	37·98	43·66
Ash	13·12	6·67	..	6·25	..	5·45	..
Fats and waxes	1·32	0·82	62·12	0·73	55·30	0·62	46·97
Total pentosans	18·86	12·83	68·01	10·68	56·61	7·92	41·99
Crude cellulose	37·90	25·33	..	19·85	..	14·99	..
Ash in above	1·30	0·83	..	0·81	..	0·55	..
Pentosans in above	7·16	4·86	..	3·79	..	2·62	..
Cellulose	29·44	19·64	66·71	14·65	49·77	11·82	40·15
Crude lignin	20·68	19·85	..	17·73	..	14·70	..
Ash in above	6·38	5·72	..	4·02	..	4·18	..
Lignin	14·30	14·13	98·81	13·71	95·87	10·52	73·57
Crude protein	6·21	3·56	57·32	2·94	47·34	2·23	35·91
*p*H	6·88	6·02		5·85		5·80	
Per cent of protein N in the residue	0·91	1·00		0·98		0·94	

TABLE XVIII

Decomposition of various constituents of rice straw No. 2 with distilled water only under waterlogged conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition					
		1 month		3 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	69·11	78·93	59·34	67·78	54·02	61·72
Ash	10·15	6·23	..	5·61	..	5·25	..
Fats and waxes	0·74	0·48	64·86	0·35	47·31	0·31	41·90
Total pentosans	22·31	16·53	74·09	14·12	63·28	12·12	54·33
Crude cellulose	43·35	34·94	..	30·36	..	26·08	..
Ash in above	0·23	0·25	..	0·21	..	0·16	..
Pentosans in above	11·22	8·54	..	7·07	..	5·23	..
Cellulose	31·90	26·15	81·96	23·08	72·35	20·69	64·86
Crude lignin	22·83	21·93	..	18·30	..	17·32	..
Ash in above	5·10	4·75	..	4·82	..	4·45	..
Lignin	17·73	17·18	96·90	13·48	76·03	12·87	72·59
Crude protein	1·83	2·59	141·60	2·24	122·40	2·45	133·90
*p*H	6·88	6·11		5·92		5·83	
Per cent of protein N in the residue	0·33	0·60		0·60		0·73	

TABLE XIX

Decomposition of various constituents of rice straw No. 1 with calcium carbonate and ammonium carbonate under waterlogged conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition					
		1 month		3 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·01	51·31	58·98	40·58	46·66	30·59	35·17
Ash	13·12	5·63	..	5·37	..	4·75	..
Fats and waxes	1·32	0·72	54·54	0·43	32·58	0·28	21·21
Total pentosans	18·86	11·38	60·34	9·45	50·09	7·01	37·16
Crude cellulose	37·90	21·36	..	16·01	..	11·82	..
Ash in above	1·30	0·82	..	0·77	..	0·58	..
Pentosans in above	7·16	4·62	..	3·15	..	1·89	..
Cellulose	29·44	16·92	57·48	12·09	41·07	9·35	31·77
Crude lignin	20·68	18·18	..	15·79	..	10·01	..
Ash in above	6·38	4·35	..	4·10	..	2·13	..
Lignin	14·30	13·83	96·74	11·69	81·75	7·91	55·33
Crude protein	6·21	3·21	51·69	2·56	41·22	1·98	31·88
*p*H	8·55	8·03		7·80		7·01	
Per cent of protein N in the residue	0·91	1·00		1·01		1·04	

TABLE XX

Decomposition of various constituents of rice straw No. 2 with calcium carbonate and ammonium carbonate under waterlogged conditions

Chemical constituents	100 gm. original straw	Material left after months of decomposition					
		1 month		3 months		6 months	
		Total residue	Percentage of original	Total residue	Percentage of original	Total residue	Percentage of original
Total dry matter	87·55	64·51	73·70	56·37	64·39	48·46	55·35
Ash	10·15	6·12	..	5·72	..	5·14	..
Fats and waxes	0·74	0·46	62·18	0·38	51·36	0·29	39·19
Total pentosans	22·31	16·32	73·14	13·75	61·63	11·13	49·89
Crude cellulose	43·35	32·00	..	26·35	..	20·20	..
Ash in above	0·23	0·23	..	0·20	..	0·18	..
Pentosans in above	11·22	8·12	..	5·82	..	3·43	..
Cellulose	31·90	23·65	74·16	20·33	63·71	16·59	52·00
Crude lignin	22·83	19·98	..	18·16	..	15·50	..
Ash in above	5·10	4·82	..	4·83	..	4·22	..
Lignin	17·73	15·16	85·51	13·33	75·19	12·28	69·26
Crude protein	1·83	2·47	135·00	2·99	163·40	3·27	178·60
*p*H	8·55	8·12		7·80		7·13	
Per cent of protein N in the residue	0·33	0·62		0·85		1·08	

As to the general course of the aerobic fermentations the results agree with the observations of most of the previous workers. A gradual decrease of fats and waxes, cellulose, hemicelluloses (pentosans), lignin, etc., was observed. The hemicelluloses disappeared more readily than cellulose during the early periods, while the order was reversed later. The mineral matter was diminished to some extent during the earlier periods but remained more or less constant during the later stages, probably due to insolubility of the residual minerals. Of all constituents the decomposition of lignins was the slowest and most incomplete.

The changes in the organic nitrogenous complexes deserve special attention. In the case of rice straw No. 1, rich in nitrogen (total nitrogen = 2·07 per cent and water-insoluble nitrogen = 0·91 per cent), in spite of decomposition there was a steady rise in the concentration of the element to a maximum of 1·7—1·9 per cent in the insoluble residue. The phenomenon appears to be a result of: (*a*) a gradual conversion of water-soluble nitrogenous substances of the plant material into insoluble form, (*b*) a relatively slower rate of disappearance of insoluble nitrogenous complexes (proteins) in comparison with that of other plant constituents at the early stages of decomposition, (*c*) the decomposition of the proteins at the same rate as other plant constituents, during the later stages. In the case of rice straw No. 2 poor in nitrogen (total nigrogen =0·61 per cent and water-insoluble nitrogen = 0·33 per cent) there was no loss of the element but both a relative and an absolute increase in the concentration of the protein fraction. When no inorganic nitrogen was supplied (Table VII), the water-soluble nitrogen fraction was gradually converted into insoluble form with the progress of decomposition and when ammonium carbonate was added (Table VIII), the inorganic nitrogen was transformed into organic form (microbial protein). In the latter case, however, the synthesis of proteins by micro-organisms was considerably greater than in the former. This leads us to conclude that microbial proteins may be synthesized from either water-soluble plant nitrogen or from inorganic salts added to the medium. The simple fact that there is no decrease in the amount of proteins, as in the case of rice straw No. 2, does not, however, prove that the insoluble plant proteins are not decomposed, but probably the degradation products of the proteins are consumed, as soon as they are formed, by the micro-organisms for the synthesis of their cell-substance. This synthetic action is related to the extent of decomposition of the plant residues, being greater when the decomposition of celluloses and hemicelluloses is also greater.

As for the influence of the various nutrient solutions employed on the rate and extent of decomposition, it has been found that the decomposition of the total organic matter as a whole, as well as of the individual constituents, takes place in the following increasing order: (*a*) with distilled water alone (Table II), (*b*) with sodium phosphate and magnesium sulphate (Table III), (*c*) with calcium carbonate and ammonium carbonate mixture (Table IV), (*d*) with ammonium carbonate alone (Table V), (*e*) with sodium nitrate (Table VI). Similar is the case with rice straw No. 2 (Tables VII and VIII).

It is found that the addition of nitrogen salts accelerates the rate and extent of decomposition of not only rice straw No. 2 (poor in nitrogen) but also to some extent of rice straw No. 1 (rich in nitrogen). This may be due to the

fact that micro-organisms prefer inorganic nitrogen to plant proteins. Similar results were obtained by Waksman and Bavendamm [1931]. The greatest decomposition of rice straw with sodium nitrate is due to its oxidizing action and the relatively rapid decomposition of lignin in this case may be due to the resulting alkalinity of the medium in which lignin is more soluble.

However, it is found that under similar conditions, the decomposition of straw No. 2 proceeds at a much slower rate. This is due to the fact that the younger plant contains more nitrogen and water-soluble substances and is less lignified. The addition of inorganic nitrogen greatly hastens the process of fermentation of rice straw No. 2, but even then it is considerably slower than that of straw No. 1 when receiving no nitrogen salts. This is due to the more lignified character and maturity of the former.

On a careful study of Tables IX-XVI, it is found that the *p*H of the media progressively falls, due to the development of acidity, and the process of decomposition is abruptly slowed down as the *p*H value approaches about 4·6, unless neutralizing agents are used. For this purpose the use of: (1) sodium phosphate and magnesium sulphate mixture (Table XI), (2) calcium carbonate (Table XII), (3) calcium carbonate and ammonium carbonate mixture (Tables XIII and XIV) and (4) ammonium carbonate (higher dose) (Table XV) was made. The observations were similar to those made by Acharya [1935]. Ammonium carbonate (higher dose) proved most successful while calcium carbonate, though present in excess, could not retard the fall of *p*H of the medium. This might be due to the formation of an insoluble deposit of lime salts of the acids on the carbonate. In the case of calcium carbonate and ammonium carbonate mixture, the rate of fall of *p*H was slower than the former case, due to presence of ammonium carbonate, but ultimately the medium became distinctly acid, due to the insufficiency of the base.

With sodium nitrate (Table XVI), however, there was no fall of *p*H during the four months of decomposition but a gradual rise from 6·88 to 8·54. After this period there was again a gradual lowering to 7·88 after six months. This can be best explained as the result of the activity of denitrifying bacteria. The nitrates are reduced to atmospheric nitrogen and there is an alkalization owing to the formation of sodium carbonate. During the later stages, however, as the process of denitrification was completed, the *p*H of the medium gradually fell as a result of accumulation of organic acids. This idea finds support from the observations of Elma, Kluyver and Dalfsen [1934] and Acharya [1935].

The *p*H of the medium is the most important factor in controlling the rate and extent of decomposition in this case, as acidity greatly inhibits the reaction. The various nutrients influence the rate and extent of decomposition in the same order as in the aerobic system, the greatest decomposition being with sodium nitrate (Table XVI). However, by comparing the results of these tables with those of Tables II-VIII, it is found that in general the rate and extent of decomposition of plant materials as a whole, as well as of the various constituents, are much slower than those under aerobic conditions. The requirement of nitrogen in this case is also much lower: the amount should be only about 0·45-0·50 per cent of the total dry matter.

A study of Tables XVII-XX shows that the waterlogged system shows intermediate behaviour between aerobic and anaerobic conditions in all res-

pects. The general behaviours of the two samples of rice straw are, however, similar in all cases, e.g. straw No. 1 decomposes more readily than straw No. 2. The fall in the *p*H of the medium as a result of acid formation is also observed, but is not so great as under anaerobic conditions. The nitrogen requirement is also not as low as for anaerobic and not as high as for aerobic decomposition, the amount necessary in this case being about 1·00-1·08 per cent of the total dry matter. The rate and extent of decomposition is intermediate between aerobic and anaerobic conditions. This is true not only of the total organic matter as a whole, but also of the individual constituents including lignin. Acharya [1935] reported that in the case of rice straw, the greatest loss of lignin takes place under waterlogged conditions, the present investigation shows that the loss of this constituent is greatest under aerobic conditions. The influence of calcium carbonate and ammonium carbonate mixture on the rate of fermentation of rice straw under waterlogged conditions has also been found to be similar to that under the other two conditions.

Summary

1. A study has been made on the decomposition of two samples of rice straw: rice straw No. 1 (younger) and rice straw No. 2 (mature) through the agency of micro-organisms present in an aqueous solution of a well-manured garden soil under aerobic, anaerobic and waterlogged conditions in presence of sufficient moisture (straw : water = 1 : 10) at the ordinary laboratory temperature.

2. The younger rice straw, No. 1, was characterized by a higher content of water-soluble substances, nitrogen, ash, and lower amounts of lignin, cellulose and pentosans in comparison with the more mature rice straw, No. 2.

3. The course of decomposition was followed by measuring the losses in the amounts of the major plant constituents (cellulose, pentosans, lignin, protein, fats, waxes, etc.) which account almost completely for the loss of the total organic matter.

4. The anaerobic process of decomposition is characterized by the formation of various organic acids, combustible gases (methane, hydrogen, etc.) and other intermediate products, while under aerobic conditions, the intermediate products, if any, are quickly oxidized to carbon dioxide and water. Decomposition under waterlogged condition shows an intermediate behaviour.

5. Decomposing organic matter tends to lower the *p*H of the medium and inhibit the fermentation process under anaerobic conditions unless proper neutralizing agents are employed. This control of acidity is of insignificant importance under aerobic conditions where the organic matter is almost completely oxidized to carbon dioxide and water. Waterlogged systems behave intermediately.

6. Of the various media employed for control of acidity under anaerobic conditions, calcium carbonate was found to be inefficient even when present in sufficient excess, whereas calcium carbonate and ammonium carbonate mixture, though effective at the earlier stages, was ineffective during the later stages, due to the insufficiency of ammonium carbonate employed. Ammonium carbonate added to the extent of 2 per cent nitrogen on the weight of

straw (1·3714 gm. of ammonium carbonate per 20 gm. of rice straw) employed was the most successful. Sodium nitrate served a dual purpose : (*a*) Denitrification and rapid oxidation of organic matter, (*b*) Alkalization of the medium, leading to the control of acidity.

7. The process of decomposition was carried out in the following media :—

(*a*) With distilled water only, (*b*) with sodium phosphate and magnesium sulphate mixture, (*c*) with calcium carbonate alone, (*d*) with calcium carbonate and ammonium carbonate (1 per cent nitrogen on the weight of straw), (*e*) with ammonium carbonate alone (2 per cent nitrogen on the weight of straw), (*f*) with sodium nitrate alone (2 per cent nitrogen on the weight of straw).

Other conditions remaining the same, the rate and extent of decomposition of the organic matter as a whole, as well as of the individual constituents, were found to increase when the above media were employed in the order mentioned.

8. The rate of decomposition was found to be greatest under aerobic, intermediate under waterlogged and least under anaerobic conditions, all other conditions remaining the same.

9. Under similar conditions, rice straw No. 1 decomposed much more rapidly and completely than rice straw No. 2, due to its more favourable chemical composition (*vide* paragraph 2 above). Addition of inorganic nitrogen salts greatly hastened the rate of decomposition of rice straw No. 2, and still more, the decomposition of rice straw No. 1.

10. For successful fermentation of rice straw under aerobic conditions about 1·7-1·9 per cent of nitrogen salts should be present in the medium, while under waterlogged and anaerobic conditions much less quantity (namely, about 1·00-1·08 per cent and about 0·45-0·50 per cent respectively) is sufficient. When the straw contains less than this amount of nitrogen, additional nitrogen salts are to be supplied to the medium (which are gradually converted into microbial cell substances with the progress of decomposition). If, on the other hand, the plant material contains greater than this amount of nitrogen, the excess is rapidly lost as waste products during the microbial processes, chiefly as ammonia.

11. Of the various plant constituents, the carbohydrate materials (cellulose, pentosans, etc.) are rapidly decomposed, while lignin, being resistant to decomposition, tends to accumulate with the progress of decomposition.

12. The residue left after decomposition becomes gradually poorer in carbohydrates and richer in lignins and protein-like substances and tends to approach the composition of humus.

ACKNOWLEDGEMENTS

The authors' thanks are due to Prof. J. C. Ghosh, D.Sc., F.N.I., Head of the Department of Chemistry (now Director, Indian Institute of Science,) and to Prof. S. N. Bose, Dean of the Faculty of Science, University of Dacca, for their kind interest and helpful criticisms during the progress of work.

REFERENCES

Acharya, C. N. (1935). *Biochem. J.* **29**, 528, 953, 1116 and 1459

Anderson, A. (1926). *Soil Sci.* **21**, 115

Bach, M. (1926). *Landw. Vers. Sta.* **104**, 245-84

Boruff, C. S. and Bushwell, A. M. (1929). *J. Ind. Eng. Chem.* **21**, 1181

——————————— (1930). *J. Ind. Eng. Chem.* **22**, 931

——————————— (1934). *J. Amer. Chem. Soc.* **56**, 826

Boussingnault, J. B. (1853). *Ann. Chem. Phys.* **37**, 5-50

Bray, M. W. and Andrews, T. M. (1924). *J. Ind. Eng. Chem.* **16**, 137-9

Bushwell, A. M. (1930). *J. Ind. Eng. Chem.* **22**, 1168

Deherain, P. P. (1884). *Ann. Agron.* **22**, 385-409

——————— (1888). *Ann. Agron.* **14**, 97-133

——————— (1902). *Traite de Agricole.* ed. 2, Paris

Egorov, M. A. (1911). *Ann. Inst. Agron.* (*Moscow*) **17**, 1-59

Elma, B., Kluyver, A. J. and Dalfsen, J. W. (1934). *Biochem. Z.* **270**, 317

Fowler, G. J. and Joshie, G. V. (1920). *J. Ind. Inst. Sci.* **3**, 39

Hebert, A. (1892). *Ann. Agron.* **18**, 536

Hebert, A. and Heim, F. (1911). *Ann. Sci. Agric.* (3) **6** (II), 337-47

Hoppe-Seylor, F. (1899). *Ztschr. Physiol. Chem.* **13**, 66-121

Hunt, T. F. (1889). III. *Agric. Expt. Sta. Bull.* **5**, 141-64

Konig, J. (1926). *Mitt. Deuts. Landw. Gessel. Stuck.* **26** & **27**

Langwell, H. and Lymn, H. (1923). *J. Soc. Chem. Ind.* (T) **42**, 280

——————————— (1932). *J. Soc. Chem. Ind.* (R) **51**, 988

Lathorp, E. C. (1912, 1). *8th Internat. Congr. Appl. Chem.* **15**, 147-51

——————— (1912, 2). *J. Chem. Soc.* **34**, 1260-3

——————— (1917, 1). *J. Frankl. Inst.* **183**, 169-206, 303-21, 465-98

——————— (1917, 2). *J. Ind. Eng. Chem.* **3**, 657-67

Norman, A. G. and Jenkins, S. H. (1933). *Biochem. J.* **27**, 818-31

Omeliansky, W. (1895). *Compt. Rend.* **121**, 653-5

——————— (1897). *Compt. Rend.* **125**, 970-5, 1131-5

Ost, H. and Wilkening, L. (1910). *Chem. Zeit.* **34**, 461-62

Phillips, M., Weihe, H. D. and Smith, N. R. (1930). *Soil Sci.* **30**, 383—90

Rege, R. D. (1927). *Ann. Appl. Biol.* **14**, 1-44

Richards and Amoore (1920). Unpublished data.

Richards, E. H. and Norman, A. G. (1927). *Biochem. J.* **25**, 1769

Rose, R. E. and Lisse, M. W. (1917). *J. Ind. Eng. Chem.* **9**, 284-7

Schwalbe, C. G. (1925). *Papier Faber.* **23**, 174

Waksman, S. A. (1926, 1). *Proc. Internat. Soc. Soil Sci.* **2**, 293-304

——————— (1926, 2). *Soil Sci.* **22**, 123-62, 221-32, 323-33, 395-406, 421-36

——————— (1927). *Cellulose Chem.* **8**, 97-103

Waksman, S. A. and Bavendamm, W. (1931). *J. Bact.* **22**, 91-102

Waksman, S. A. and Diehm, R. A. (1931). *Soil Sci.* **22**, 97-117, 119-39

Waksman, S. A. and Gerretsen, F. C. (1931). *Ecology* **12**, 33-60

Waksman, S. A. and Heukelekian, H. (1925). *J. Biol. Chem.* **66**, 323-42

Waksman, S. A. and Hutchings, I. J. (1936). *Soil Sci.* **42**, 119-30
Waksman, S. A. and Skinner, C. E. (1926). *J. Bact.* **12**, 57-84
Waksman, S. A. and Tenney, F. G. (1926). *Soil Sci.* **22**, 395
——————————— (1927). *Soil Sci.* **24**, 275-83, 317-34
——————————— (1928). *Soil Sci.* **26**, 155-71
——————————— (1929). *Soil Sci.* **28**, 55-84. 315-40
——————————— (1930). *Soil Sci.* **30**, 143-60
Waksman, S. A., Tenney, F. G. and Stevens, K. R. (1928). *Ecology* **9**, 126-44

II. A NOTE ON THE CHANGES IN THE METHOXYL AND NITROGEN CONTENT OF LIGNIN OF RICE STRAW DURING ITS DECOMPOSITION BY MICRO-ORGANISMS

BY

S. S. GUHA SIRCAR

S. C. DE

AND

H. D. BHOWMICK

Department of Chemistry, University of Dacca, Dacca

(Received for publication on 28 December 1938)

RECENT researches have supported the prevalent idea that lignin, the resistant constituent of plants, takes the most prominent part in the formation of humus, during their micro-biological decomposition. In part I of the present investigation also, it has been found that plant residues become gradually richer and richer in lignin with the progress of decomposition as the latter breaks down only slowly in comparison with other plant constituents. However, the decomposition of this constituent has been found to be the greatest under aerobic, intermediate under waterlogged and the least under anaerobic conditions. Fuchs [1926] summarized the experimental evidences of various investigators which tended to establish the role of lignins as the mother substances of humus or of humic acids. He stated that the transformation is accompanied by the splitting off of methoxyl groups, the formation of phenolic, hydroxyl and carboxyl groups and self-condensations. Various other investigators, such as Hoppe-Seylor [1899], Page [1932] and Waksman and others [1932-34] have also held that humic acid is formed by the combination of lignin or modified lignin complexes with proteins during the micro-biological decomposition of plant residues. Hebert [1892, 1893] and Deherain [1902] were the first to suggest the conception of humus as a mixture of lignin and protein, the former being the resistant part of the plant residues and the latter synthesized by micro-organisms inhabiting them. According to Hobson and Page [1932] the nitrogen in humus is associated with humic matter in some manner which does not allow of its removal by methods which ordinarily remove physically bound nitrogen compounds. A series of ligno-protein complexes were prepared by Waksman and Iyer [1932-33] which behaved in most respects, such as colour, solubility in alkalies, chemical reactivity and resistance to attack by micro-organisms like the typical humic acids, humic matter or alphafraction of humus.

Waksman and Smith [1934] have observed the gradual removal of methoxyl groups in lignin in the process of natural decomposition of organic residues under aerobic but more specially anaerobic conditions, but an increase in the relative amount of ash and organic nitrogenous compounds. The lignin molecule is modified considerably during decomposition even when it is not destroyed as a whole. Under aerobic conditions, however, the lignin molecule as a whole is attacked, and the methoxyl content of the residual lignin is not modified to any marked extent.

An attempt has been made in this paper to follow the changes undergone by the lignin fraction during the progress of micro-biological decomposition. For this purpose the lignins obtained from rice straw decomposed under various conditions of the medium under aerobic, anaerobic and waterlogged conditions (as described in part I) were analysed for: (*i*) methoxyl content, and (*ii*) nitrogen.

Now the methoxyl, which is a characteristic group of lignin, is not present in constant proportion in various preparations, but its amount varies from source to source of the lignin as was shown by Fuchs [1926], and even in the same plant at different stages of growth as was shown by Beckmann [1923]. Beckmann also found that not only is there an increase in the lignin content of plants with an increase in maturity, but the amount of methoxyl also increases.

Experimental

The lignin preparations used for the present study were all obtained from rice straws No. 1 and No. 2, as described in part I, at various stages of decomposition and the same methods were employed for their isolation to obtain comparative results. In part I the method of isolation of lignin has been described. The sulphuric acid method has two advantages: (*i*) The lignin is isolated quantitatively and free from carbohydrates, and (*ii*) it contains all the methoxyl groups intact.

It has been recently shown by Harris, Sherrard and Mitchel [1934] that fuming hydrochloric acid method of isolation of lignin as recommended by Willstatter and Zechmeister [1931] is open to objection because part of the methoxyl is lost during this treatment.

The methoxyl values were determined by Zeisel's method as modified by Perkin [1903]. The nitrogen was estimated by micro-Kjeldahl method as only small quantities of samples were available. The distillation apparatus is described in Pregl's [1924] '*Quantitative micro-analysis*' (translated by Fyleman). The results of analysis calculated per 100 gm. of lignin employed are expressed in Tables I-IV.

Table I

Changes in the methoxyl content of lignin of rice straw No. I with decomposition under aerobic, anaerobic and waterlogged conditions

Treatment	Original lignin (per cent)	After 3 months (per cent)	After 6 months (per cent)
Aerobic with distilled water only	8·47	7·17	6·87
Aerobic, with $CaCO_3$ and $(NH_4)_2CO_3$	..	7·78	6·34
Waterlogged, with distilled water only	..	5·60	4·89
Waterlogged, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	5·82	5·31
Anaerobic, with distilled water only	8·47	4·69	3·85
Anaerobic, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	4·75	4·01

TABLE II

Changes in the methoxyl content of lignin of rice straw No. 2 with decomposition under aerobic, anaerobic and waterlogged conditions

Treatment	Original lignin (per cent)	After 3 months (per cent)	After 6 months (per cent)
Aerobic, with distilled water only	9·42	7·25	6·62
Aerobic, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	8·47	7·82
Waterlogged, with distilled water only	..	6·49	5·63
Waterlogged, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	6·52	5·87
Anaerobic, with distilled water only	..	5·59	4·89
Anaerobic, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	6·01	5·65

TABLE III

Changes in the nitrogen content of lignin of rice straw No. 1 with decomposition under aerobic, anaerobic and waterlogged conditions

Treatment	Original lignin (per cent)	After 3 months (per cent)	After 6 months (per cent)
Anaerobic, with distilled water only	1·25	1·28	1·51
Anaerobic, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	1·31	1·63
Waterlogged, with distilled water only	..	1·30	1·72
Waterlogged, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	1·39	1·87
Aerobic, with distilled water only	..	1·50	2·37
Aerobic, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	1·68	2·58

TABLE IV

Changes in the nitrogen of lignin of rice straw No. 2 with decomposition under aerobic, anaerobic and waterlogged conditions

Treatment	Original lignin (per cent)	After 3 months (per cent)	After 6 months (per cent)
Anaerobic, with distilled water only	1·11	1·13	1·36
Anaerobic, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	1·28	1·49
Waterlogged, with distilled water only	..	1·30	2·15
Waterlogged, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	1·38	2·48
Aerobic, with distilled water only	..	1·67	2·85
Aerobic, with $CaCO_3$ and $(NH_4)_2\ CO_3$	..	1·73	2·98

DISCUSSION OF RESULTS

A study of Tables I-IV shows that the methoxyl content of lignin of rice straw No. 2 (mature) is higher than that of lignin of straw No. 1 (less mature), but the nitrogen content is lower. It has been found that the presence of nitrogen in lignin of original plant materials cannot be eliminated even after repeated treatments with sulphuric acid. This may be due to two reasons : (1) The nitrogen may be an integral part of the molecule, (2) Under the influence of concentrated acid the proteins may be rendered partly insoluble (humin).

Lignin from straw No. 1 contains more nitrogen than that from No. 2. This may be due to a greater amount of protein being precipitated by the mineral acids if the second assumption is correct.

A glance at Tables I and II will show that with the progress of decomposition there is a decided loss of the methoxyl content of lignin under aerobic and anaerobic as well as under waterlogged conditions, the loss being greatest under anaerobic, intermediate under waterlogged, and least under aerobic conditions. It is also found that the loss of methoxyl is not so great when the medium contained a mixture of calcium carbonate and ammonium carbonate than when the straw decomposed alone. Possibly the acidity of the medium helps the splitting off of the methoxyl group.

These facts are supported by the observations of Waksman and Smith [1934] who found that aerobic organisms attack the lignin molecule as a whole and completely destroy it without affecting the methoxyl content of the material. Under anaerobic conditions, however, the decomposition of lignin is the least but the methoxyl group is rapidly split off. The waterlogged system shows an intermediate behaviour.

On the other hand, a study of Tables III and IV shows that nitrogen content of lignin increased with increasing periods of fermentation, the increase being most marked under aerobic, intermediate under waterlogged and least under anaerobic conditions. This may probably be due to: (*i*) the greater activity of aerobic organisms resulting in the systhesis of greater amounts of microbial proteins, or (*ii*) the greater activity of aerobic organisms in the synthesis of ligno-proteins.

It is also to be noted that the addition of nitrogen as ammonium carbonate in the decomposing rice straw also increases the formation of ligno-protein complexes.

Attempts were made to measure the rate of formation of humic acids (the alkali-soluble and acid-insoluble fraction of the decomposing organic matter) with the progress of decomposition of rice straw. But as both the original lignin and lignin-humic acid mixture of the decomposed straw were somewhat soluble in alkalies, these attempts did not throw much light on the problem. Karrer and Boding-Wieger [1921, 1923] demonstrated that when acetyl bromide is allowed to act upon plant material, practically all of the organic constituents, except 'humified matter', are brought into solution, forming acetylated and methylated products; and he used this method for the separation of the undecomposed plant residues from the 'humified' substances. But it was found that this action of acetyl bromide is extremely slow and at least four to five days contact with the hot reagent was necessary before much effect was produced.

The action of this reagent and also the conductometric titrations of humified lignins are under investigation.

Summary

1. A study has been made of the changes in the content of nitrogen and methoxyl in the lignin preparations (obtained from straw No. 1 and straw No. 2) at various stages of decomposition under aerobic, anaerobic and waterlogged conditions

2. There is an increase in the nitrogen and decrease in the methoxyl content of lignin with the progress of decomposition. When the plant materials are decomposed with a mixture of calcium carbonate and ammonium carbonate, the loss of methoxyl is less but the nitrogen content is higher.

3. Loss of methoxyl is the greatest under anaerobic, intermediate under waterlogged, and the least under aerobic conditions. The reverse is the case with the increment of nitrogen content.

Acknowledgments

The authors' thanks are due to Prof. J. C. Ghosh, D.Sc., F.N.I., Head of the Department of Chemistry (now Director, Indian Institute of Science, Bangalore) and to Prof. S. N. Bose, Dean of the Faculty of Science, University of Dacca, for their kind interest and helpful criticisms during the progress of work.

REFERENCES

Beckmann, E., Liesche, O. and Lehmann, F. (1923). *Biochem. Ztschr.* **139**, 491-508
Deherain, P. P. (1902). *Traite de Chimie Agricole*, ed. 2, Paris
Fuchs, W. (1926). *Die Chemie des Lignins*, Berlin
Harris, E. E., Sherrard, E. C. and Mitchel, R. L. (1934). *J. Amer. Chem. Soc.* **56**, 889-93
Herbert, A. (1892, 1). *Ann. Agron.* **18**, 536-50
——— (1892, 2). *Compt. Rend. Acad. Sci.* **115**, 1321-3
——— (1893). *Expt. Sta. Record* **5**, 141-58
Hobson, R. P. and Page, H. J. (1932). *J. Agric. Sci.* **22**, 497-515
Hoppe-Seylor, F. (1899). *Ztschr. Physiol. Chem.* **13**, 66-121
Karrer, P. and Boding-Wieger, B. (1921). *Helv. Chim. Acta.* **4**, 700
——— (1923). *Helv. Chim. Acta.* **6**, 817-22
Page, H. J. (1932). *J. Agric. Sci.* **22**, 291-6
Perk in, W. H. (1903). *Proc. Chem. Soc.* **19**, 1370
Pregl, F. (1924). *Quantitative Micro-analysis.* (Translated by E. Fyleman). London, J. & A. Churchil. Page 96
Waksman, S. A. and Iyer, K. R. N. (1932, 1). *J. Wash. Acad. Sci.* **22**, 41-50
——— (1932, 2). *Soil Sci.* **34**, 43-80
——— (1933). *Soil Sci.* **36**, 57-82
Waksman, S. A. and Smith, H. W. (1934). *J. Amer. Chem. Soc.* **56**, 1225
Willstatter, R. and Zehméister, L. (1931). *Ind. Eng. Chem. Anal. Ed.* **3**, 253

STUDIES ON THE CHEMICAL CONSTITUENTS OF INDIAN LATERITIC AND RED SOILS

I. DETERMINATION OF FREE SESQUIOXIDE COMPONENTS

BY

S. P. RAYCHAUDHURI

AND

M. SULAIMAN

Agricultural Chemistry Section, Dacca University

(Received for publication on 28 September 1939)

Introduction

THE determination of free alumina and free iron oxide is important for the proper characterization of red soils. Bauer's [1898] work showing that the laterites of Seychilles was similar to the so-called bauxite of Hessy in Germany not merely drew attention to the fundamental chemical character of laterite, but left little else than details to be done by others on the nature of laterites. Dealing with some aspects of tropical soils, Hardy [1935] writes : ' Evidently the present usage of the term laterite by petrologists is inexact, and the modern definition has come to mean a highly aluminous and highly hydrated residual rock product, usually also rich in hydrous iron oxides and containing other characteristic components '. It has been used in this sense by Harrison [1933], by many other early soil investigators and geologists. Mention may also be made here of the views of Warth and Warth [1903], who, as a result of their detailed chemical examination of many typical Indian laterites, write : ' Further, the results show the term laterites has a distinct meaning throughout the many varieties of this rock. Laterite is bauxite in various degrees of purity from the richest wochenite down to such specimens, in which the free alumina has entirely disappeared '. The determination of free alumina and free iron oxides at different horizons of the red soil profiles of India was accordingly undertaken.

Different methods have been suggested by different workers for the determination of the sesquioxide components, viz. by Van Bemmelen [1933], Tamm [1922], Mattson [1931], Hardy [1931], Drosdoff and Truog [1935], and recently by Truog and co-workers [1937]. Tamm's ammonium oxalate method seems to be very drastic treatment and of the other methods the one most commonly used is that devised by Hardy. Recent investigations however indicate that methods of Drosdoff and Truog (which has been later modified by Truog and co-workers), is most convenient for the determination of free iron oxide components of soils. Accordingly, as a preliminary stage of this work, the data of the percentages of sesquioxide components of soils were obtained following the methods of Hardy and of Drosdoff and Truog.

Experimental

I. Determinations based on the principle of alizarin adsorption used by Hardy [1931]

In this procedure the amount of alumina and iron oxide uncombined with silica is determined by the adsorption of alizarin, the determinations being based on the fact that the iron oxide in the soil can adsorb alizarin sulphonate only before ignition, whilst the alumina gel can adsorb alizarin sulphonate only after ignition.

Two portions were taken, each of mass one gram (70 I.M.M.). One portion was heated to dull redness (800°C.) for six minutes in a silica crucible covered by a lid, the other was not heated. Each portion was introduced into a Pyrex glass test tube containing 20c.c. of 0·5 per cent solution of sodium alizarin sulphonate (alizarin—S)*. Adhering particles were washed down the sides of the tubes with 10 c.c. of 80 per cent boric alcohol. The tubes were heated with simple condensers and then heated in a gently boiling water bath for ten minutes. After settling for five minutes, the supernatant liquid in each tube was decanted into a Buchner funnel containing filter paper pulp, and filtered by suction into a filtering flask. The solid material was treated with 25 c.c. boric alcohol, boiled, and the whole suspension poured into the funnel and filtered by suction. Excess of dyestuff was washed out of the sediment with a little boiling boric alcohol followed by boiling distilled water.

The adsorbed dyestuff from the stained material was extracted by means of a saturated aqueous solution of sodium oxalate containing sufficient free oxalic acid to impart a *p*H value of 3·8. The concentration of the dyestuff in the extract was measured in a Duboscq colorimeter against a standard. From the results both the alumina content and the ironoxide content of the soils could be calculated.

A blank oxalate extraction on 1 gm. of the material, both fresh and ignited, omitting the dyestuff treatment, was performed in all cases to correct for the iron solubility of ferruginous materials.

II. Determinations based mainly on the principles devised by Drosdoff and Truog [1935]

(*A*) *Separation and determination of free silica and free alumina*

Two gm. of soil (70 I.M.M.) were digested with 2 per cent sodium carbonate solution in a 250 c.c. Pyrex beaker at about 70°C. for 10 hours with frequent stirring by glass rod to dissolve free silica and free alumina. The content of the beaker was decanted and washed several times with 0·05 *N* hydrochloric acid, using an Ecco centrifuge. The washings were analysed for free silica and free alumina.

(*B*) *Determination of free iron oxide*

The residue containing soil from (*A*) was suspended in 250 c.c. water in a 500-c.c. bottle and saturated with sulphuretted hydrogen for half an hour. It was then made just alkaline with normal ammonium hydroxide, shaken for half an hour, acidified with decinormal hydrochloric acid, adding an excess

* 100 c.c. of the solution contained about 80 c.c. of 80 per cent alcohol saturated with boric acid (*p*H 3·2).

of about 50 c.c. to dissolve the iron sulphides completely, and then warmed on water bath to drive off the sulphuretted hydrogen and coagulate the suspension which was then transferred to the centrifuge tubes and the supernatant liquid was collected by decanting after centrifuging. The residue was washed several times with 0·05 *N* hydrochloric acid by centrifuging. The supernatant liquid and washings were collected and the quantity of iron oxide was determined in the solution. Soils containing large amounts of free iron oxide may require more than one treatment for complete removal of iron oxide.

Results

Table I shows the results of the determination of free alumina and free iron oxide by Hardy's method with some typically Indian red soil samples on profile basis, whilst Table II gives the comparison of the data of free sesquioxides obtained by the methods of Hardy and of Drosdoff and Truog. The percentages of free silica obtained by the latter method is also included in the same Table II. The figures for the percentages of free alumina have been calculated by the new calculating factor (0·1) given by Hardy [Hardy and Rodrigues, 1939].

TABLE I

Percentages of free sesquioxide components obtained by the Hardy's method

Soil No.	Locality	Depth	Oven dry basis		
			Per cent free Al_2O_3	Per cent free Fe_2O_3	Per cent total free $Al_2O_3 + Fe_2O_3$
1p	Dacca, Bengal . .	0 in.—6 in. .	1·02	2·14	3·16
2p	Dacca, Bengal . .	6 in.—2 ft. 3in.	1·80	3·89	5·69
3p	Dacca, Bengal . .	2 ft. 3 in.—4 ft.	2·40	4·90	7·30
4p	Suri, Bengal . .	0 ft.—1 ft. .	1·56	2·22	3·78
5p	Suri, Bengal . .	1 ft.—1 ft. 6 in.	1·81	2·35	4·16
6p	Suri, Bengal . .	1 ft. 6 in.—4 ft.	2·08	3·33	5·41
7p	Suri, Bengal . .	Below 13 ft. .	1·98	1·05	3·03
8p	Suri, Bengal . .	Below 13 ft..	1·08	0·93	2·01
10p	Bidar, Hyderabad .	0 ft.—1 ft. .	6·62	2·68	9·30
13p	Bidar, Hyderabad .	0 in.—1 ft. 6 in.	5·92	3·00	8·92
14p	Didgi, Hyderabad .	Surface layer	2·50	4·77	7·27
15p	Didgi Hyderabad . ..	51 ft.—54 ft.	7·06	5·12	12·18
16p	Jairabad, Hyderabad .	0 in.—1 ft. 6in.	4·98	2·68	7·66
18p	Himayetsagar, Hyderabad	0 in.—3 in. .	0·91	1·67	2·58
19p	Himayetsagar, Hyderabad	3 in.—1 ft. 6 in.	0·72	3·78	4·50
20p	Himayetsagar, Hyderabad	1 ft. 6 in.—4 ft.	1·40	1·05	2·45

TABLE I—*contd.*

Soil No.	Locality	Depth	Oven dry basis		
			Per cent free Al_2O_3	Per cent free Fe_2O_3	Per cent total free $Al_2O_3 + Fe_2O_3$
21p	Himayetsagar, Hyderabad	1 ft. 6 in.—4 ft.	3·04	2·09	5·13
23p	Telankheri, Nagpur, C. P.	0 in.—2 in. .	10·30	3·92	14·22
24p	Telankheri, Nagpur, C. P.	2 in.—2 ft. 6 in.	8·38	6·85	15·23
26p	Telankheri, Nagpur, C.P.	13 ft.—16 ft..	1·08	1·04	2·12
27p	Telankheri, Nagpur, C. P.	16 ft.—21 ft..	0·54	2·47	3·01
33p	Raipur, C. P. . .	0 in.—4 in. .	6·33	3·47	9·80
34p	Raipur, C. P. . .	4 in.—1 ft. 5 in.	6·74	3·97	10·71
35p	Raipur, C. P. . .	1 ft. 5 in.—4 ft.	7·62	4·68	12·30
36p	Raipur, C. P. . .	0 in.—6 in. .	5·82	2·10	7·92
37p	Raipur, C. P. . .	0 in.—6 in. .	4·09	2·53	6·62
38p	Labhandi, Raipur, C. P.	0 in.—8 in. .	4·38	2·51	6·89
39p	Labhandi, Raipur, C. P.	8 ft.—10 ft. .	3·32	1·55	4·87
42p	Alisagar, Hyderabad .	0 ft.—1 ft. .	3·24	4·37	7·61
43p	Alisagar, Hyderabad .	1 ft. and down	5·14	3·78	8·92
53p	Nilgiri Hills (1)–3000 ft. a.s.l.	0 in.—1 ft. 8 in.	1·86	3·25	5·11
54p	Nilgiri Hills (1)–3000 ft. a.s.l.	1 ft. 8 in.—3 ft.	1·94	4·40	6·34
55p	Nilgiri Hills (1)–3000 ft. a.s.l.	Below 54p .	1·44	3·78	5·22
56p	Nilgiri Hills (2)–5000 ft. a.s.l.	0 ft.—1 ft. .	9·53	7·19	16·72
57p	Nilgiri Hills (2)–5000 ft. a.s.l.	1 ft.—2 ft. .	9·62	7·37	16·99
58p	Nilgiri Hills (2)–5000 ft. a.s.l.	2 ft.—6 ft. .	11·64	6·90	17·54
59p	Nilgiri Hills (3)–7000 ft. a.s.l.	0 in.—1 ft. .	13·70	7·99	21·69
60p	Nilgiri Hills (3)–7000 ft. a.s.l.	1 ft.—3 ft. .	20·84	10·00	30·84
61p	Nilgiri Hills (3)–7000 ft. a.s.l.	3 ft.—4 ft. 6 in.	17·34	7·18	24·52
62p	Nilgiri Hills (3)–7000 ft. a.s.l.	4 ft. 6 in.—6 ft.	17·01	7·07	24·08
63p	Guntur, Madras . .	0 in.—9 in. .	9·04	6·23	15·27
64p	Guntur, Madras . .	9 in.—(5 ft.—6 ft.)	2·96	4·95	7·91

TABLE II

Comparison of the data of the free sesquioxide obtained by the methods of Hardy and of Drosdoff and Truog

Soil No.	Oven dry basis				
	Hardy's method		Drosdoff and Truog's method		
	Per cent free Al_2O_3	Per cent free Fe_2O_3	Per cent free SiO_2	Per cent free Al_2O_3	Per cent free Fe_2O_3
33p . .	6·33	3·47	0·0919	0·495	6·01
34p . .	6·74	3·97	0·1038	0·757	6·42
35p . .	7·62	4·68	0·1349	0·497	7·37
53p . .	1·86	3·25	0·1197	0·522	4·74
54p . .	1·94	4·40	0·1715	0·764	6·70
55p . .	1·44	3·78	0·1503	0·477	5·70
56p . .	9·53	7·10	0·1826	0·522	7·78
57p . .	9·62	7·37	0·1954	1·065	8·21
58p . .	11·64	6·90	0·2174	1·007	7·42
59p . .	13·70	7·99	0·1847	0·819	11·51
60p . .	20·84	10·00	0·1086	0·517	15·47
61p . .	17·34	7·18	0·1193	0·363	11·67
62p . .	17·01	7·07	0·1614	0·396	10·22

Discussion

It will be seen from Table I that the percentages free iron oxides in the soils bear no relation to the percentages of free alumina. It is also found that in the case of the Dacca profile the contents of both alumina and of iron oxide increase down the profile. In the case of the profile from the Suri, the percentages of both oxides show a maximum at an intermediate depth. The profile from Himayetsagar shows a minimum percentage of free alumina at intermediate depth, whilst the percentage of free iron oxide shows a maximum at an intermediate depth. In the case of Telankheri profile at Nagpur, the percentage of free alumina decreases down the profile, whilst the percentage of free iron oxide shows a maximum at an intermediate depth. In the case of the Raipur profile in the Central Provinces both the percentages of alumina and iron oxide increase as the depth of the profile increases. The profiles from the Nilgiri Hills, in general, show a maximum concentration of alumina and iron oxide at an intermediate depth of the profile.

Except in the case of soils from Nagpur and Nilgiri Hills (2) and (3), and the top layer of Guntur soils the percentage of free alumina in the soil samples is never very high, so that, judged from the point of view of Bauer

all the so-called-lateritic soils of India in Table I, cannot be classed as laterites or lateritic. This conclusion also appears to be evident from a consideration of the SiO_2/Al_2O_3 and $SiO_2/Al_2O_3 + Fe_2O_3$ ratios of the clay fractions*. The SiO_2/Al_2O_3 ratios of clay fractions are often greater than 2 which suggest that the soils cannot be classed as laterites or lateritic in the sense of the definition by Martin and Doyne [1930], although they are known to be such by the departments of Agriculture of the respective provinces from where the soils were collected.

The data in Table II indicate that the percentages of the free alumina obtained by Hardy's method are much higher than those obtained by the method of Drosdoff and Truog. On the other hand, the percentages of iron oxides obtained by Hardy's method are somewhat smaller. There appears to be no parallelism between the results obtained by the two methods. In view of the considerations set forth above, it is felt desirable to examine more closely the validity and usefulness of different methods for estimating the free sesquioxide components in Indian lateritic soils. Such investigations are in progress.

Thanks of the authors are due to Prof. J. C. Ghosh for his kind interest during the progress of this work and to the Imperial Council of Agricultural Research by whose grant the soil samples used in the present investigation were collected. Thanks are also due to the Bengal Government for the award, to one of the authors (M. S.), of a research scholarship which has enabled him to carry out this work.

Summary

1. The percentages of free sesquioxides in Indian lateritic and red soils have been determined on profile basis following the methods devised by Hardy and by Drosdoff and Truog.

2. The percentages of free iron oxides obtained by Hardy's method are somewhat smaller than those obtained by the method of Drosdoff and Truog.

3. The percentages of free alumina obtained by Hardy's procedure are, on the other hand, much higher than those obtained by the other method.

4. There is no correlation between the results obtained by the two methods.

REFERENCES

Bauer, M. (1898) *Neuss Jahrb. F. Min. Geol. U. Pal.* **2**, 163-219
Drosdoff, M. and Truog, E. (1935) *J. Amer. Soc. Agron.* **27**, 312-17
Hardy, F. (1931) *J. Agric. Sci.* **21**, 150-66
Hardy, F. (1935). *Trans. 3rd. Internat. Cong. Soil Sci.* **2**, 153
Hardy, F. and Rodrigues, G. (1939). *Soil. Sci. 48*, 361-84,
Harrison, J. B. (1933). *The Katamorphism of igneous rocks under humid tropical conditions.* Imp. Bur. Soil. Sci., Rothamsted Exptl. Sta., Harpenden, England
Martin, F. J. and Doyne, H. C. (1930). *J. Agric. Sci.* **20**, 135
Mattson, S. (1931). *Soil Sci.* **31**, 311-31
Tamm, O. (1922). *Medd. Statens Skogforsokenst.* **19**, 387-404
Truog, E., *et al.* (1937). *Proc. Soil Sci. Soc. Amer. 1936*, **1**, 101-12
Van Bemmelen, J. M. (1933) (cp. W. Bujakowsky and C. Treschow, k ∅ benhavn, (1933), 121-41)
Warth, H. and Warth, F. J. (1903). *Geol. Mag.* **4**, 155

* Unpublished work.

THE DEPTH OF THE SURFACE LAYER OF THE SOIL TAKING PART IN THE DIURNAL EXCHANGE OF MOISTURE WITH THE AIR LAYERS NEAR THE GROUND

BY

A. K. MALLIK, M.Sc., B.Sc. (Ag.), Assoc. I.A.R.I.
Assistant Agricultural Meteorologist, Meteorological Office, Poona

(Received for publication on 15 August 1939)

Introduction

IT has been shown in a series of papers [Katti, 1935 ; Ramdas, 1934 ; Ramdas *et al.*, 1934, 1935, 1936, 1938, 1939] that during the clear season at Poona when the ' surface layer ' of the soil is so dry as to contain hygroscopic moisture only, the soil loses moisture by evaporation into the atmosphere from morning till afternoon but from the afternoon till the next morning it absorbs from the atmosphere more or less all the moisture lost during the earlier part of the day. Thus there is a regular sequence of maximum and minimum moisture content epochs of the soil at about the minimum and the maximum temperature epochs respectively. The exchange of moisture is greatest in the b ack cotton soil, much less in the alluvial soil and practically absent in quartz powder. The exchange of moisture is confined to the surface layer of the soil but the exact th ickness of the layer involved in the diurnal exchange of moisture remained to be found out. This problem received attention during the clear season of 1939. The clear season at Poona is characterized by cloudless skies, a large diurnal range of temperature and of relative humidity and feeble air movements. During the period March to June 1939 some experiments were made to find out the exact thickness of the ' surface layer ' of the soi exchanging moisture with the air layers near the ground. A short note on the subject describing only the results in the case of the black cotton soil of Poona was published recently. In the present paper the results obtained with some other typical Ind.an soils are discussed in detail.

Materials and methods

A series of cylindrical brass vessels 4·75 cm. in diameter were made with their tops open and the bottoms closed. The series of cylinders were made with increasing heights for exposing soils with depths rang ng from 1 to 40 mm. The soils under study, thoroughly air-dried and passed through a 1 mm. sieve, were filled in these pots, the actual depths of soil being 1, 2, 3, 4, 5, 10, 20 and 40 mm. respectively. These vessels were kept embedded in the ground with their tops fully exposed. It was arranged that the surface of the soil in each experimental vessel was at the same level as that of the

soil outside. On selected clear days these vessels were exposed in the open and weighed at intervals to find out the maximum and minimum weights of the soil due to the gain or loss of moisture in the process of exchange with the atmosphere. The following soils were included in the study :—

(i) Black cotton soil of Poona.
(ii) Red soil of Bangalore.
(iii) Alluvial soil of Lyallpur.
(iv) Sandy soil of Trivandrum.

Statement of results

(*a*) *Exchange of moisture by the black cotton soil of Poona as shown by the maximum and minimum weights*

Poona soil was filled in the vessels ranging from 1 to 40 mm. in depth and these were exposed to the open on a series of clear days in March, April and May 1939. The maximum and minimum weights were obtained by weighing these vessels with the soil at 6 A.M. in the morning and at 2 P.M. in the afternoon respectively. Tables I (*a*), (*b*), (*c*) and (*d*) give the difference between the maximum and minimum weights for various depths of soil on the different occasions.

Table I(*a*)

Black cotton soil of Poona (maximum-minimum weight in gm.)

Depth of soil (mm.)	23-3-1939	24-3-1939	25-3-1939	26-3-1939	Mean
1	0·1945	0·1952	0·1902	0·1918	0·1929
2	0·3532	0·3612	0·3610	0·3808	0·3640
3	0·4640	0·5016	0·5248	0·4986	0·4972
4	0·5818	0·5688	0·5544	0·6140	0·5798
5	0·6918	0·6656	0·6304	0·6532	0·6600
10	0·7808	0·7708	0·7634	0·7732	0·7720
20	0·7402	0·7418	0·7576	0·7104	0·7373
40	0·7216	0·6808	0·7302	0·7096	0·7108

TABLE I(*b*)

Black cotton soil of Poona (maximum-minimum weight in gm.)

Depth of soil (mm.)	5-4-1939	6-4-1939	7-4-1939	8-4-1939	Mean
1	0·2748	0·2576	0·2828	0·2684	0·2079
2	0·3262	0·3140	0·3462	0·3624	0·3372
3	0·4608	0·4462	0·4470	0·4932	0·4618
4	0·5542	0·5984	0·5296	0·5998	0·5705
5	0·7630	0·7958	0·7428	0·7065	0·7520
10	0·9436	0·9920	0·9912	0·9296	0·9641
20	0·9008	0·9546	0·9008	0·8994	0·9139
40	0·9088	0·9420	0·8600	0·8784	0·8973

TABLE I (*c*)

Black cotton soil of Poona (maximum-minimum weight in gm.)

Depth of soil (mm.)	24-4-1939	25-4-1939	26-4-1939	Mean
1	0·2488	0·2452	0·1592	0·2177
3	0·5964	0·5028	0·3600	0·4864
5	0·8838	0·7320	0·5244	0·7135
10	0·9242	0·7572	0·5264	0·7363
15	0·9468	0·7304	0·4816	0·7229
20	0·9024	0·7288	0·4672	0·6995
25	0·8876	0·7268	0·4680	0·6941
30	0·8874	0·7244	0·4660	0·6926
35	0·8748	0·7195	0·4604	0·6849
40	0·8420	0·7150	0·4610	0·6727

TABLE I (*d*)

Black cotton soil of Poona (maximum-minimum weight in gm.)

Depth of soil (mm.)	1-5-1939	2-5-1939	3-5-1939	Mean
1	0·2104	0·2407	0·1836	0·2116
3	0·3263	0·3486	0·3046	0·3265
5	0·6810	0·6948	0·6624	0·6794
10	0·8506	0·8876	0·7060	0·8147
15	0·8300	0·8596	0·6908	0·7901
20	0·8108	0·8132	0·6824	0·7688
25	0·8054	0·8084	0·6788	0·7642
30	0·7986	0·8002	0·6742	0·7577
35	0·7914	0·7908	0·6740	0·7521
40	0·7788	0·7826	0·6724	0·7446

(*b*) *Exchange of moisture by the red soil of Bangalore as shown by the maximum and minimum weights*

As in the case of Poona soil, the vessels filled with the red soil of Bangalore were exposed during the period 24th April 1939 to 3rd May 1939 and the maximum and minimum weights were determined by weighing at 6 A.M. and 2 P.M. respectively. Tables II(*a*) and (*b*) give the difference between the maximum and minimum weights in gm. for various depths.

TABLE II (*a*)

Red soil of Bangalore (maximum-minimum weight in gm.)

Depth of soil (mm.)	24-4-1939	25-4-1939	26-4-1939	Mean
1	0·0304	0·0238	0·0276	0·0273
3	0·0952	0·0556	0·0396	0·0635
5	0·1472	0·0968	0·0734	0·1058
10	0·2532	0·1826	0·1334	0·1897
15	0·3568	0·2320	0·1656	0·2515
02	0·3996	0·2736	0·1884	0·2872
25	0·3668	0·2584	0·1698	0·2650
30	0·3516	0·2472	0·1594	0·2527
35	0·3262	0·2398	0·1598	0·2419
40	0·3128	0·2308	0·1522	0·2319

TABLE II (*b*)

Red soil of Bangalore (maximum-minimum weight in gm.)

Depth of soil (mm.)	1-5-1939	2-5-1939	3-5-1939	Mean
1	0·0338	0·0280	0·0248	0·0289
3	0·0506	0·0564	0·0546	0·0539
5	0·0902	0·0946	0·1002	0·0950
10	0·1784	0·1806	0·1748	0·1779
15	0·2686	0·2752	0·2213	0·2550
20	0·3198	0·3244	0·2936	0·3126
25	0·3104	0·3128	0·2600	0·2944
30	0·3068	0·2898	0·2484	0·2817
35	0·2924	0·2880	0·2422	0·2742
40	0·2868	0·2864	0·2400	0·2711

(*c*) *Exchange of moisture by the alluvial soil of Lyallpur as shown by the maximum and minimum weights*

The vessels were filled with alluvial soil of Lyallpur and exposed during the period 5th April 1939 to 13th May 1939. The maximum and the minimum weights were determined by weighing these vessels at 6 A.M. and 2 P.M. respectively. Tables III (*a*) and (*b*) give the difference between the maximum and minimum weights in gm. for various depths of soil.

TABLE III (*a*)

Alluvial soil of Lyallpur (maximum-minimum weight in gm.)

Depth of soil (mm.)	5-4-1939	6-4-1939	7-4-1939	8-4-1939	Mean
1	0·0464	0·0260	0·0342	0·0346	0·0353
2	0·0520	0·0544	0·0668	0·0508	0·0560
3	0·0600	0·0816	0·0960	0·0764	0·0785
4	0·0834	0·1436	0·1618	0·1338	0·1307
5	0·1176	0·1840	0·1992	0·1536	0·1636
10	0·1347	0·2006	0·2312	0·1884	0·1887
20	0·1956	0·3208	0·3496	0·2774	0·2859
40	0·1856	0·3056	0·3304	0·2584	0·2700

TABLE III (*b*)

Alluvial soil of Lyallpur (maximum-minimum weight in gm.)

Depth of soil (mm.)	8-5-1939	9-5-1939	10-5-1939	11-5-1939	12-5-1939	13-5-1939	Mean
1	0·0260	0·0166	0·0280	0·0204	0·0276	0·0292	0·0246
3	0·0456	0·0964	0·0448	0·0548	0·0985	0·0684	0·0681
5	0·0828	0·1804	0·1322	0·0848	0·1626	0·1946	0·1396
10	0·1660	0·2028	0·1645	0·1147	0·2096	0·2648	0·1871
15	0·2072	0·2867	0·2004	0·1642	0·2998	0·3264	0·2474
20	0·2438	0·3404	0·2336	0·1818	0·3964	0·4022	0·2987
25	0·2546	0·3498	0·2390	0·1940	0·4092	0·4002	0·3075
30	0·2314	0·3444	0·2310	0·1832	0·3408	0·3796	0·2851
35	0·2014	0·3284	0·2272	0·1706	0·3246	0·3468	0·2665
40	0·2000	0·3022	0·2096	0·1602	0·3018	0·3242	0·2497

(*d*) *Exchange of moisture by the sandy soil of Trivandrum as shown by the maximum and minimum weights*

The vessels were lastly filled with sand and exposed to the open during the period 30th May 1939 to 2nd June 1939. The maximum and the minimum weights were determined by weighing these vessels at 6 A.M. and 2 P.M. respectively.

Table IV gives the difference between the maximum and the minimum weights in gm. for various depths of soil on different days.

TABLE IV

Sandy soil of Trivandrum (maximum-minimum weight in gm.)

Depth of soil (mm.)	30-5-1939	31-5-1939	1-6-1939	2-6-1939	Mean
1	0·0000	0·0000	0·0000	0·0000	0·0000
2	0·0000	0·0000	0·0000	0·0000	0·0000
3	0·0000	0·0000	0·0000	0·0000	0·0000
4	0·0000	0·0000	0·0000	0·0000	0·0000
5	0·0003	0·0004	0·0000	0·0000	0·0002
10	0·0030	0·0042	0·0002	0·0002	0·0019
15	0·0289	0·0316	0·0162	0·0142	0·0227
20	0·0296	0·0380	0·0164	0·0148	0·0247
25	0·0388	0·0484	0·0246	0·0226	0·0341
30	0·0412	0·0508	0·0316	0·0302	0·0383
35	0·0464	0·0540	0·0398	0·0324	0·0431
40	0·0470	0·0548	0·0400	0·0328	0·0437

Discussion

An examination of the above tables will show that on clear days the 'surface layer' of the soil is constantly exchanging moisture with the air layers near the ground. The amplitude of this moisture exchange is found to be greatest in the black cotton soil of Poona and least in the sandy soil of Trivandrum. Also the amplitudes of the soils studied are in about the same relation as found by Ramdas and Katti [1934, 2].

It is also seen from the tables that in all the soils examined the amount of moisture exchanged goes on increasing till a certain depth is reached beyond which the amplitude of variation does not show much change with further increase in the depth of soil.* The above depth indicates the actual thickness of the surface layer which is taking part in the diurnal exchange of moisture between the soil and the air layers near the ground. The exact depth of soil involved is different in the different types of soils. Table V gives the depth of soil exchanging moisture with the atmosphere in the case of the four types of soils studied.

Table V

Type of soil	Depth of soil involved in the diurnal exchange of moisture (mm.)	Mean maximum amplitude of variation in weight gm. per sq. cm.
1. Black cotton soil of Poona	10	0·0460
2. Red soil of Bangalore	20	0·0169
3. Alluvial soil of Layallpur	25	0·0167
4. Sandy soil of Trivandrum	More than 40	0·0025

Thus it is seen that although the amount of moisture exchanged is maximum, the depth to which this moisture exchange extends is minimum in the Poona soil. On the other hand, in the sandy soil of Trivandrum, the moisture exchange penetrates much deeper although the amount of moisture exchanged is very small. As is well known, the black cotton soil contains a very high clay fraction and is therefore the least porous, whereas the sandy soil of Trivandrum is free of clay and is therefore the most porous of the soils examined. It appears, therefore, that the exact depth of soil involved in the diurnal exchange of moisture increases with the porosity of the soil.

* From the tables it will be noticed that there is a slight tendency for the difference between the maximum and the minimum weights of the soils to decrease with depth below the depth of maximum difference. This secondary effect was noticed systematically in all the experiments and is presumably due to heat conducted to the interior layers of the soil samples through the sides of the metallic vessels. This secondary effect will be examined in detail during the next clear season.

Summary and conclusions

On clear days there is an exchange of moisture between 'surface layer' of soil containing hygroscopic moisture only and the air layers near the ground. The amplitude of the diurnal exchange of moisture is maximum in the black cotton soil of Poona and minimum in the sandy soil of Trivandrum.

The depth to which this moisture exchange extends is different in different soils being smallest in the black cotton soil of Poona and greatest in the sandy soil of Trivandrum, the red soil of Bangalore and the alluvial soil of Lyallpur having intermediate values.

Experiments with the different components of the soil obtained by mechanical analysis will be undertaken during the next clear season.

My best thanks are due to Dr. L. A. Ramdas, Agricultural Meteorologist, for suggesting the problem and for guidance during the course of the work.

References

Katti, M. S. (1935). *Current Sci.* **4**, 419

Ramdas, L. A. (1934). *Current Sci.* **2**, 445

Ramdas, L. A. and Katti, M. S. (1934, 1). *Ind. J. Agric. Sci.* **4**, 923

——————————— (1934, 2). *Current Sci.* **3**, 24

——————————— (1935). *Current Sci.* **3**, 612

——————————— (1936). *Ind. J. Agric. Sci.* **6**, 1163

Ramdas L. A. and Mallik, A. K. (1938). *Current Sci.* **6**, 452

——————————— (1939). *Current Sci.* **4**, 164

CONVERSION OF CANE MOLASSES INTO MANURE BY THE BIOLOGICAL METHOD AND THE RESULTS OF THE CROPPING TESTS WITH THE MANURES PREPARED (1938-39)

BY

H. D. SEN, M.Sc., PH.D.(LOND.), D.I.C.

Biochemist, Imperial Institute of Sugar Technology, India, Cawnpore

(Received for publication on 10 August 1939)

THE application of molasses to soil for use as manure has been a subject of research for a fairly long time and the uncertainty in the results so far obtained by different workers may be ascribed to the fact that molasses on fermentation in the soil lead to the production of acids, which retard the plant growth. In cases of application of molasses in soil in comparatively small doses, where the alkalinity of the soil is sufficient to cope with the acid produced as a result of fermentation, deleterious effect is not so very evident, but when molasses is applied in heavy doses the depressant action is very significant.

Gainy [1923], working on the influence of hydrogen-ion concentration on the growth and fixation of nitrogen by cultures of azotobacter, finds *p*H 5·9 to 6·0 as the limiting *p*H below which no fixation of nitrogen can take place. Soil having acidity below 6·0 showed complete absence of azotobacter. If, however, calcium carbonate is added to reduce the acidity, such soil was found to favour the growth of azotobacter. Addition of more acids leads to its complete disappearance.

Hence it is very likely that when molasses is applied directly into the soil, particularly in heavy doses, there will be nitrogen loss instead of nitrogen fixation due to greater acid accumulation.

Paramanik, Rao and Lal [1937], working on cane yield, observed the beneficial effect of using molasses along with ammonium sulphate, particularly in alkaline soils. This leads one to conclude that whereas there is nitrogen loss when heavy dose of carbohydrate material is applied, this is partially avoided when the carbohydrate is applied in conjunction with a certain proportion of nitrogenous material, i.e. there is a carbon-nitrogen (C : N) ratio.

The mechanism of reaction taking place in the soil on direct application of molasses seems, therefore, to be very complicated, which is rendered more unsurmountable by the varied soil flora present—the reactions taking place leading to uncertain results—sometimes nitrogen fixation and in other cases nitrogen loss.

One would naturally ponder whether molasses has a potential value as manure or its biological products—yeast, salts of organic acids and nitrogenous decomposition products.

Viswanath and Suranarayana [1932], working with *Halianthus annus* of the giant yellow variety got striking results by directly injecting aqueous extracts of dried yeast, farmyard manure and sewage effluent.

Narayana [1932] pointed out that extracts of fermented farmyard manure are more effective in stimulating plant growth than fresh farmyard manure.

Desai and Fazal-ud-Din [1938] have carried out experiments in which the presence of yeast has led to the thriving of symbiotic soil flora, such as *Colstrydium acetobutylicum*, in soil. These do not thrive on carbohydrate materials as such, but become active in presence of yeast.

Bhaskaran and Subramanyan [1937] showed that, whereas organic acids have definite deleterious effect, their calcium salts led to greater nitrogen fixation.

Tinkler [1937] stated that apex of rootlets produce substances capable of regulating the growth and that these substances could be transferred to other seedlings. A wide search for a ready source of these compounds revealed that they are contained in small quantities of urine.

Kogl [1937] established the constitution of the active substance to be of the class of indolyl acetic, propionic, butyric acids, etc. and their esters. Skatole which is β methyl indole has been proved to be active and so are α and β napthelene acetic acids.

The fermented molasses solution contains yeast, calcium salts of acetic, propionic, butyric acids, etc. and also nitrogen decomposition products, such as indole, acetic, butyric, propionic acids and their esters and also skatole and as such are likely to be more beneficial to plant growth than molasses itself.

The main difficulty in the use of molasses directly in the soil lies in the fact that it is to be applied in a diluted form and a large bulk of water is necessary for the purpose. The application of such diluted solution in the field invariably spreads an unbearable smell all along the water channel leading such polluted water, and particularly in cases where there is an accumulation of dilute molasses solution in pits.

The complex bacterial population of the soil and the uncertain results that might happen if molasses is directly applied and the problem of conversion of large quantities of molasses into manure in a comparatively short time led the author to devise a simple method, the details of which will be discussed in the present paper.

The working of the process depends on the increased production of yeast cell body by carrying on fermentation at the neutral point under conditions of heavy aeration the acidity being intermittently neutralized with milk of lime. The course of fermentation under the above circumstances is diverted not to the production of alcohol and carbon dioxide but to the theoretical preliminary formation of aldol and subsequent formation of products like glycerol which is further taken up by the yeast cells to increase their body. Thus increased yield of yeast is obtained with simultaneous production of calcium salts of organic acids.

The prevention of loss of nitrogen by administering molasses along with ammonium sulphate or the existence of carbon-nitrogen ratio may be explained by the theory that as a result of fermentation of sugars present in molasses yeast is initially formed, which is produced in increased yield due to the application along with it of small quantities of ammonium sulphate or phosphate, acting as nutrient.

That aeration with neutralization of the acidity so as to maintain a *p*H of 7·0 during fermentation gives increased yield of yeast has been confirmed by a study of the yeast yield where instead of milk of lime sodium carbonate solution was added to neutralize the acidity. The addition of 1-5 per cent of ammonium sulphate gave definite increased yeast yields (about three times the control) while addition of ammonium phosphate gave the highest yield (about six times). Thus it seems that there is not only carbon-nitrogen ratio but carbon-nitrogen-phosphorus ratio.

Although the duration of aeration in the preliminary experiments was eight hours every day for three days, i.e. 24 hours, an aeration for a period of 72 hours, i.e. continued aeration for three days was found to be most beneficial.

Process of manufacturing manure from molasses

The process of manufacturing manure from molasses consists in constructing three masonry tanks 10-ft.×10-ft.×8-ft. (4,984 gallons) having pipe lines from an air blower, the main pipe line being 2-in. in diameter, connected to three parallel 1-in. pipe lines in the middle of each tank. The central 1-in. pipe line in each tank has three ½-in. pipe lines running at right angles to it and bending downwards to 1-ft. from the base so as not to disturb the sludge collected at the bottom. Each tank is provided with a centrifugal pump for the transference of the fermented liquor to the next tank.

Seventy-five maunds of molasses (88 brix) is diluted with 3,000 gallons of water (13 brix) in the first tank to which 75 maunds of filter press mud is thoroughly ncorporated. Sixty gallons of active wash made three days earlier by adding to a solution of 1 md. of molasses in 60 gallons of water in a wooden cask of that capacity to which 12 gallons (1/5th) of active wash (preparged from pure yeast, *S. Ellipsoidus*, in the Laboratory) is added. This is propagated in six casks containing 360 gallons of active wash. One-fifth is left in the fermenting casks. Two hundred and forty gallons (5 maunds molasses) is added to the wash prepared above. Half a maund of ammonium phosphate (Nicifos of Imperial Chemical Industries containing 17 per cent nitrogen and 17 per cent phosphorus is added to the wash and aeration started with intermittent addition of lime (12 Be) every four hours. At the end of 24 hours' aeration the fermented liquor is transferred to the second tank leaving the sludge, a second dose of ½ md. ammonium phosphate added and aeration started with intermittent addition of lime every four hours. In the meantime the first tank is charged with fresh 75 mds. of molasses and 75 mds. of filter press cake and 3,000 gallons of water. Two hundred and forty gallons of active wash is further added with ½ md. ammonium phosphate and aeration started in the first tank for 24 hours. On the third day the wash from the second tank is transferred to the third tank and the wash from the 1st tank transferred to the second.

A fresh charge of 75 mds. of molasses and 75 mds. of filter press cake in 3,000 gallons of water and 240 gallons of active wash (5 mds. molasses) is made on the third day in the first tank and ½ md. ammonium phosphate added. The first charge of liquor which has now reached the third tank and completed three days' continued aeration is run into the fields having also considerable manurial value. The second charge of fermented wash is transferred to the third tank and ½ md. ammonium phosphate added and aerated for 24 hours.

On the fourth and fifth days no fresh charge of molasses is made but there is transference of the third charge into the second and third tanks.

On the sixth day the sludge collected in all the three tanks is transferred to shallow cemented masonry beds for sun-drying and manure eventually packed in bags and sent to the cane fields. The fermented liquor, which is quite harmless after treatment, is sent through water channels to the cane fields. At the end of a week thus 240 mds. of molasses and an equal quantity of filter press mud will receive treatment yielding about 40 per cent manure on the total weight, i.e. 172 mds. besides 9,000 gallons of fermented liquor having high manurial value.

Expenses—	Rs.	As.
Cost of exhaust molasses 240 mds. @ 4 annas per md.	60	0
Filter press cake @ 6 pies per md.	7	8
Nicifos @ 6/- per md., 4½ mds. containing 17 per cent N and 17 per cent P	27	0
Lime 40 mds. @ 8 annas per md.	20	0
Electricity @1 anna per unit 24 KWH.	1	8
Labour, 2 coolies @ 5 annas per day for six days	3	12
Total Rs.	119	12

∴ Cost of 170 mds. of manure (N. 1·0 per cent) 119-12 = Rs. 120.

∴ Cost per md. of manure—-/11/3 = 12 annas only.

Experimental

Sen and Dutta [1937] and Sen [1938] have studied the nitrogen distribution in the sludge and the fermented liquor where 50 mds. of molasses was diluted with 6,000 gallons of water under conditions where acids were allowed to accumulate as compared with those where the acids were neutralized with milk of lime (12 Be) using a mixed bacilli obtained by self-fermentation of molasses consisting of *B. coli*, yeast, acetic, and lactic bacteria. In case of acid fermentation the supernatent fermented liquor was taken to an adjoining tank and neutralized with lime. The sludge separated in both tanks were collected, sun-dried, weighed and analysed. The data obtained are shown in tables I(*a*)-(*c*).

Table I (*a*)

Description	Weight taken	Dry matter per cent	Total N per cent	Total N in dry substance in lb.
Original molasses	50 mds.	73·8	0·514	15·64
1. Manure by acid fermentation	10—10	94·7	1·684	13·17
2. Manure from chemical treatment tank	21—00	100·0	0·0043	0·07
3. Exit Water	6,000 gall.	..	2·6 parts per 100,000 parts	1·56
				14·80

TABLE I (*b*)

Description	Weight taken	Dry matter per cent	Total N per cent	Total N in dry substance in lb.
Original molasses	50 mds.	73·8	0·514	15·64
1. Manure obtained by acid fermentation	11 mds.	100·0	1·54	13·94
2. Manure obtained from chemical treatment tank	18 mds., 8 srs.	100·0	0·14	2·06
3. Exit water . . .	6,000 galls.	..	2·5 parts in 100,000 parts	1·50
				17·50

TABLE I (*c*)

Fermentation with intermittent neutralization with milk of lime

Original molasses	50 mds.	73·8	0·514	15·64
1. Manure by intermittent addition of lime with heavy aeration	24 mds., 20 srs.	100·0	1·23	24·0
2. Exit water . . .	6,000 galls.	..	8·24 parts in 100,000 parts	4·9
				28·94

The above figures indicate that, in cases where fermentation is carried out without aeration, organic acids are allowed to accumulate and the wash is saturated with carbon dioxide gas, only 84·0-89·1 per cent of the total nitrogen present in the original molasses is fixed in the sludge, 10·4 per cent remain in the fermented liquor and the rest is lost ; while in cases of intermittent neutralization with heavy aeration there is distinct evidence of nitrogen fixation, the total increase in the sludge and the fermented liquor being 185 per cent. i.e. nearly double the original nitrogen content.

Effect of using pure yeast instead of mixed bacteria

In the later experiments it was found that the nitrogen content of the sludge increased definitely by using a pure culture of yeast instead of a mixed bacteria. The percentage of nitrogen in the sludge increased where there was preponderance of yeast cells. Whereas by using mixed bacteria with intermittent addition of lime a sludge containing 0·92 per cent nitrogen was obtained, pure yeast gave a sludge with a nitrogen content of 1·84 while a sludge

with a nitrogen content of 2·1 per cent was obtained when equal mixtures of molasses and filter press cake were fermented with lime addition. The waxes, gums and organic matters present in the filter press cake gave comparatively more nutrient for the growth of the yeast body.

The nitrogen balance in molasses and manure obtained from a mixture of molasses and press cake using pure yeast are given in table II.

TABLE II

Fermentation of a mixture of molasses and filter press cake with aeration and intermittent addition of lime using pure yeast

Description	Weight taken (mds.)	Dry matter per cent	Dry matter (md.)	Nitrogen per cent on dry matter	Total N in dry substance in mds.
Molasses	50	82·0	41	0·27 (on wet molasses)	0·1107
Press mud	50	30·0	15	0·9	0·0014
					0·1121
1. Manure with intermittent lime addition and aeration	53	33·0	17·6	1·46	0·25
2. Exit water . . .	6,000	..	..	9·9 parts in 100,000 parts	0·072
					0·322

There is thus evidence of still greater nitrogen fixation when molasses is used in conjunction with filter press cake using pure yeast.

Yield of yeast when fermentation is carried out at the neutral point with aeration

To ascertain whether by carrying out the fermentation at the neutral point, there is increase in the yeast yield a series of experiments were undertaken by Sen and Dutta [1938]. In these experiments milk of lime was replaced by a solution of sodium carbonate so that the results may not be vitiated by the presence of calcium salts. The yeast obtained was separated by centrifuging and wet yields (moisture 50 per cent) were determined after washing the yeast sediment twice with distilled water to remove the sodium salts. The data obtained are given in table III.

TABLE III

Percentage yield of manure obtained at different specific gravities calculated on molasses and total sugars assuming that molasses contain 60 per cent sugars

Treatments	Percent yield								
	Specific gravity 1·0528			Specific gravity 1·0340			Specific gravity 1·0178		
	Weight* of sediment in 100 c.c. (gm.)	Per cent yield on sugars 12 gm. present in 100 c.c.	Per cent yield on molasses 20 gm. present in 100 c.c.	Weight of sediment in 100 c.c. (gm.)	Per cent yield on molasses 6·6 gm. present in 100 c.c.	Per cent yield on molasses 11 gm. present in 100 c.c.	Weight of sediment in 100 c.c. (gm.)	Per cent yield on sugars 5 gm. present in 100 c.c.	Per cent yield on molasses 8·4 gm. present in 100 c.c.
1. Control— Fermentation without aeration or neutralization	1·126	9·4	5·6	1·765	26·7	16·0	1·431	28·6	17·0
2. Fermentation with aeration and neutralization with sodium carbonate	1·824	15·2	9·1	2·339	35·4	21·2	1·741	34·8	20·7
3. Fermentation with aeration and neutralization with sodium sulphite	1·478	12·3	7·3	2·332	34·5	21·1	2·214	44·2	26·3
4. Fermentation with ammonium sulphate and aeration and neutralization with soda	3·372	28·1	16·8	3·321	50·0	30·1	2·705	54·1	32·2
5. Fermentation with ammonium phosphate 1 per cent neutralization with soda	6·723	56·1	33·6	8·346	126·4	75·8	8·11	162·0	96·5

*moisture 50 per cent

The results indicate that :

1. The yield of yeast is least when the fermentation is carried out without aeration or intermittent neutralization of sodium carbonate.

2. The yield of yeast increases about $1\frac{1}{2}$ times under aeration and intermittent neutralization with sodium carbonate during 72 hours.

3. The increase in the yeast production is not so much when neutralization is carried out with sodium sulphite although it is decidedly greater by at least one third the yield obtained without aeration or neutralization.

4. The use of ammonium sulphate 1-5 per cent on molasses augments the yield to about three times that obtained without aeration or neutralization.

5. The use of ammonium phosphate as neutrient in the proportion of 1-5 per cent molasses increases the yield to about six times that obtained without aeration or neutralization.

6. The yield of yeast increases with increasing dilution of molasses solution. Molasses solution fermented as 1·017 gave yeast yield two to three times as great as that obtained at 1·052. Molasses solution fermented at 1·034 gave yield twice as great.

The preliminary experiments show that yeast yield is definitely increased when fermentation is carried out at the neutral point with aeration and that ammonium phosphate and ammonium sulphate (1-5 per cent) augment it considerably (six to three times), the former having more marked result.

On the basis of the above experiments manures have been prepared from molasses under the following conditions :—

1. Molasses fermented with intermittent addition of lime at the interval of four hours with continuous aeration during 72 hours.

2. Molasses and filter press cake mixed in equal proportions fermented with intermittent addition of lime at the interval of every four hours with continuous aeration during 72 hours.

A portion of the fermented liquor after separation of the sludge was concentrated in each case. Samples of the sludge and fermented wash concentrates have been set apart for complete analysis of organic and inorganic constituents. The analyses are in progress.

A qualitative micro-test of the samples will reveal whether besides yeast there are present calcium salts of acetic, propionic, butyric acids and also indol and skatole, acetic, propionic, butyric acids or their esters which are active plant harmones.

An investigation is also in progress to determine how the course of fermentation is diverted under conditions of heavy aeration and constant neutralization of the acidity with alkali salts. It is presumed that under the above conditions the course of fermentation is diverted leading to less production of alcohol and more of yeast cell body.

Cropping experiments with the manures prepared from molasses 1938-39 experiments

Mr. P. B. Richards, I. A. S., Director of Agriculture, United Provinces, took a great interest in the newly prepared manure and allotted a piece of land, about three acres at the Kalyanpur farm, United Provinces. The plot selected had not received any manurial treatment.

There were nine treatments with six replications 40 ft. × 31-5 ft. and each plot split into three sub-plots having three varieties of cane—Co 313, Co 312 and Co 331—early, medium and late varieties. The manures were applied in randomised blocks distributed according to the schemes shown below.

The distance between two sub-plots was 7 ft. longitudinally and 5 ft. on the broad side. Two rows of cane between varietal treatment in each sub-plot were left out during harvesting, while two rows in between two sub-plots received no manurial treatment. The area of each sub-plot was 1/30th of an acre which was sub-divided into three smaller plots having different cane variety, and measuring 1/90th of an acre.

Particulars

Date of sowing	2nd March 1938
Previous irrigation to sowing	20th February 1938
After sowing, irrigation on	6th March 1938
	3rd April 1938
	29th April 1938
	22nd May 1938

Area of plots.—Length 46 ft. × breadth 31-5 ft.

Rows in each.—9. Three rows of each variety in treatment.

Treatment A.—Molasses fermented with lime to give 60 lb. nitrogen per acre.

Treatment B.—Molasses fermented with lime to give 120 lb. nitrogen per acre.

Treatment C.—Molasses *plus* filter press cake fermented with lime, 60 lb. nitrogen per acre.

Treatment D.—Molasses *plus* filter press cake fermented with lime, 120 lb. nitrogen per care.

Treatment E.—Molasses (direct application) to supply 60 lb. nitrogen per acre.

Treatment F.—Molasses (direct application) to supply 120 lb. nitrogen per acre.

Treatment G.—Castor cake to supply 60 lb. nitrogen per acre.

Treatment H.—Castor cake to supply 120 lb. nitrogen per acre.

Treatment I.—Control.

a—Co 313, early-ripening variety.
b—Co 312, medium-ripening variety.
c—Co 331, late-ripening variety.

The plots being 1/30th acre, molasses (0·25 per cent nitrogen) was added at 10 mds. and 20 mds. respectively to supply 60 and 120 lb. nitrogen. The prepared manures (calculated taking nitrogen content at 1·0 per cent) were added in the proportion of 2·5 and 5 mds. respectively to supply 60 and 120 lb. nitrogen per acre. Castor cake (4 per cent nitrogen) was supplied at 0·75 and 1·25 mds. respectively.

The *p*H of the Kalyanpur soil, as determined by the electrolytic method was found to be 7·3 while Hillige's comparator gave 7·3. The soil may, therefore, be taken as almost neutral soil with slight leaning towards alkalinity.

East
North
South.
West
area = 1/80th acre.
5 ft.
40 ft.
31·5 ft.
7ft.
5ft.

Preliminary observations

Rate of growth

Systematic measurements of the seedlings were made in the months of June and July 1938 to study the comparative response to different manures. Six seedlings from each sub-plot were carefully measured and the mean height for six replications was recorded. In each case the measurement (in feet) was made from the root to the top of the stalk.

Table IV

Measurement of seedlings in feet

Treatments	Co 313			Co 312		Co 331	
	May	June	July	June	July	June	July
A .	10·63	16·0	52·4	18·6	57·3	14·07	53·2
B .	10·62	...	...	...	...	...	...
C .	13·5	15·5	51·4	18·7	56·6	14·3	52·9
D .	12·87	18·7	51·4	17·9	57·0	14·6	53·3
E .	11·91	15·9	51·0	16·9	56·6	14·7	52·5
F .	11·62	12·6	48·6	13·4	51·0	12·4	51·6
G .	11·63	15·4	53·5	18·1	57·8	15·3	52·3
H .	15·91	16·4	57·3	21·9	64·5	16·5	52·3
I .	12·7	13·7	50·7	16·4	55·0	13·7	50·8

On studying the rate of growth of cane seedlings it may be noticed that direct application of molasses has a definite retarding effect, especially in treatment F when molasses is applied at the rate of 120 lb. nitrogen per acre although the retarding effect is not so evident in treatment E when molasses is used in small doses that is 60 lb. nitrogen per acre. The rate of growth is much less than even the control plot. Manures A, B, C and D prepared by the biological method from molasses and also from mixtures of molasses and filter press cake show no retarding effect. On the contrary it had definite beneficial effect even when applied in as high dose as 120 lb. nitrogen per acre.

Rate of germination

The observations made by the Superintendent, Kalyanpur Farm on the rate of germination are :—

Treatments . . .	A	B	C	D	E	F	G	H	I
Percentage of germination .	Good	Good	Fair	Good	Fair	Bad	Good	Good	Fair

Susceptibility to disease

The observations made by the Superintendent, Kalyanpur Farm are given in Table V.

TABLE V

Treatments	Co 313	Co 312	Co 331
A molasses manure 60 lb. N per acre	Fair growth, better than control, tillering good	Fair growth, internodes shorter	Stunted canes, fair tillering, more leafy growth
B molasses manure 120 lb. N per acre	Growth very good, tillering same as castor cake	Very long canes, less leafy growth, average tillering	White ant attack marked throughout, lodging at places, canes long
C molasses + filter press cake, 60 lb. N per acre	Growth poorer, mosaic infection at places, tillering average	Tillering better	Mosaic attack, tillering average
D molasses + filter press cake, 120 lb. N per acre	Canes thick, development fair, leaf not healthy	Lodging, very long canes, tillering very good	Leafy growth, shorter canes, lodging, tillering fair
E molasses, direct application, 60 lb. N per acre	Growth poor, leaves pale and sickly, tillering average similar to control	Growth poor, root system weak, tillering poor	Termite attack vigorous
F molasses, direct application, 120 lb. N per acre	White ant attack, development bad	White ant attack, lodging throughout	Leaves paler at tops, shows lack of nutrition, lodging
G castor cake, 60 lb. N per acre	Good leafy growth, tillering fair, no lodging	Fair and less leafy growth	Canes fairly long
H castor cake, 120 lb. N per acre	Well developed good growth, tillering average	Best growth, lodging at places	Very good growth, lodging at places
I control . . .	Poor growth and tillering .	Growth and tillering poor .	Tillering poor, top borer attack

The data obtained confirm the observation that treatments E and F (direct molasses application) gave poorer growth, sickly leaves, white ant and termite attack. The growth with prepared manures (A, B, C, D) is generally good although with Co 331 there has been evidence of white ant and mosaic attack. Each variety Co 313, Co 312, and Co 331—early, medium and late varieties—was tested for maturity by the study of the top-middle-bottom brix and purity ratio of the juice. When the ripening tests were satisfied each cane variety was analysed for total sucrose in cane and the average of six replications was taken into account for calculation. The harvesting was undertaken soon after the analysis and the average of six replications determined. Co 313 was harvested on 26th January 1939, Co 312 on 21st February 1939 and Co 331 on 1st March 1939.

Calculations were made for each cane variety on the basis of the total sucrose in cane and cane yield obtained as average of six replications of cane yield per acre, sucrose per acre, excess of cane yield per acre over control, excess of cane yield per acre over F (molasses, direct application in heavy doses @ 120 lb. nitrogen per acre), excess sugar yield per acre over control, and excess of sugar yield per acre over F.

TABLE VI

Co 313—EARLY RIPENING VARIETY.

Percentage of total sucrose in cane obtained under different manurial treatments : Co 313 : tests carried out after verification of the maturity by the top-bottom-brix ratio and also top-bottom-purity ratio by Java method

Treatments	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Average	Increase or decrease over control
A	14·48	14·21	14·14	14·15	13·4	14·57	14·13	+1·14
B	14·30	14·50	13·82	15·07	12·73	12·61	13·83	+0·83
C	13·91	14·74	14·75	12·84	12·72	13·86	13·80	+0·81
D	13·21	13·47	13·98	11·26	13·11	12·90	12·98	—0·01
E	13·30	13·34	14·29	11·63	13·28	12·62	13·07	+0·08
F	13·93	13·44	13·30	11·78	11·48	14·04	12·98	—0·01
G	14·35	13·52	14·16	9·80	13·75	14·39	13·32	+0·33
H	12·28	13·78	12·88	13·46	13·89	14·10	13·39	+0·40
I	13·22	11·88	13·51	14·98	11·70	12·70	12·99	...

The percentage of total sucrose in cane, taking the average of six replications, varies from 12·98 to 14·13, i.e. by 1·13 per cent only. It may, therefore, be said that on maturity, the percentage of total sucrose in cane tends to a maximum constant figure irrespective of manurial treatments. The four treatments with molasses manure A, B and C, however, show slight increase. With D it is the same as control. Molasses (direct application) in light and heavy doses E and F have given the same total sucrose as the control. The increase in case of castor cake treated plots G and H, though higher than the control is nearly half the increase obtained in the case of concentrated manures.

TABLE VII

Yield of cane per plot 1/90th acre. Co 313 (Harvested on 26th January 1939)

Treatment	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Average
	Mds.	Mds.	Mds.	Mds.	Mds.	Mds.	Mds.
A	8—31	7—29	8—33	8—11	6—31	8—2	8—2
B	7—33	8—5	8—10	8—4	8—0	7—1	7—35
C	7—16	6—11	7—2	7—36	8—17	6—2	7—20
D	7—2	7—8	6—37	8—17	7—33	7—27	7—20
E	6—35	8—11	9—24	9—16	9—17	8—29	8—28
F	4—18	4—25	3—8	6—15	5—18	7—27	5—15
G	8—10	6—16	6—28	8—34	7—34	8—3	7—27
H	8—1	7—32	7—17	9—19	8—18	8—26	8—14
I	6—14	6—12	7—20	6—13	7—34	7—0	6—15

The cane yield in 1/90th acre plots shows a definite depressant effect in plot F treated with heavy dose of molasses (1 md. 20 srs.). The concentrated manures A, B, C, D show uniformly an increase over the control plot (+1 md. 25 srs., +1 md., +25 srs.,+25 srs.). The deleterious effect is not observed in plot E, treated with light dose of molasses (+1 md. to 33 srs.). The cane yield in case of castor cake is nearly the same as the concentrated manures.

TABLE VIII

Calculations on the cane yield and total sucrose per acre—Co 313

Treatments]	Canes yield in 1/90th acre	Canes yield per acre	Per cent sucrose	Sucrose per acre	Excess yield per acre over control	Excess cane yield per acre over F	Excess sugar yield per acre over control	Excess sugar yield per acre over F
	Mds.	Mds.		Mds.	Mds.	Mds.	Mds.	Mds.
A	8—2	724·5	14·13	102·47	+130·8	+241·5	+22·59	+39·88
B	7—35	707·75	13·83	98·02	+93·55	+214·75	+18·14	+35·43
C	7—20	675·0	13·80	93·45	+61·30	+192·0	+13·57	+30·86
D	7—20	675·0	12·98	87·61	+61·30	+192·0	+7·73	+25·02
E	8—28	783·0	13·07	103·33	+169·3	+300·0	+23·45	+40·76
F	5—15	483·0	12·98	62·59	—130·7	...	—17·29	...
G	7—27	690·75	13·32	92·00	+77·0	+207·75	+22·12	+29·41
H	8—14	751·5	13·39	100·57	+138·0	+268·5	+20·69	+37·98
I	6—35	613·72	12·99	79·88	...	+130·7	...	+17·98

Thus the concentrated manures A, B, C and D have given an increase in the cane yields per acre by nearly 100 mds. as compared with the control (+111·0, +94·0, +61·3 and +61·3 mds.) and 200 mds. as compared with molasses in heavy doses (+261·5, +227, +182 and +182 mds.). Molasses (direct application) in small doses does not show any deleterious effect (+170 mds. more than control, +300 mds. more than F). Molasses in heavy doses show definite depressant effect (—110 mds. less than the control). Castor cake behaves similarly to the concentrated manures (+87, +148 mds. respectively as compared with control and +207 and +268 mds. respectively as compared with F).

The increase in the total sucrose yield per acre with concentrated manures comes to about 20 mds. (+22·59, +18·14, +13·57 and +78·73) as compared with the control while molasses, direct application in heavy doses (F), give a deficit of 17·29 mds. The deleterious effect of molasses is not evident when applied in light doses (E) the increase in yield of sugar per acre being 23·45 mds. Castor cake gave 22·12 and 20·69 mds. increase respectively over the control. Comparing with F (molasses in heavy doses) there is increase in yield in cases of A, B, C, D treatments (+39·88, +35·43, +30·86 and +25·82 mds. respectively) and so with castor cake (+29·41, 37·98 mds.). Even the control shows an increase by 17·98 mds.

TABLE IX

Co 312—MEDIUM-RIPENING VARIETY

Percentage of total sucrose in cane obtained under different manurial treatments
Tests carried out after verification of the maturity

Treatments	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Average
A	9·0	12·70	12·99	11·9	13·94	12·79	12·22
B	11·72	7·00	13·41	12·19	10·69	11·52	11·09
C	12·10	10·12	12·84	12·80	13·79	11·99	12·27
D	12·81	10·75	13·40	13·06	13·66	9·61	12·21
E	12·49	11·65	12·84	12·98	12·92	12·26	12·52
F	12·44	12·55	12·52	12·35	11·89	12·15	12·31
G	10·19	13·55	13·49	11·91	7·46	13·14	11·62
H	11·92	11·77	7·10	10·88	9·24	12·73	10·56
I	9·31	13·07	13·08	13·69	12·79	12·90	12·47

Taking the cane variety Co 312 the total sucrose in cane is found to be more or less the same as control and is not affected by various manurial treatments. In Co 313 some differences, though very slight, was discernable. The castor cake treated plots, however, show a definite lowering due to more leafy growth.

TABLE X

Harvesting of Co 312 (1/90 acre)

Treatments	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Average
	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.
A	11—26	11—3	12—15	11—37	12—32	10—1	11—26
B	10—37	12—0	12—1	11—18	12—17	12—30	11—37
C	10—18	10—8	10—21	16—11	11—11	10—27	11—23
D	9—3	10—12	10—30	10—25	13—15	11—15	10—37
E	9—6	10—9	12—17	11—24	10—24	11—16	10—36
F	8—25	8—0	9—37	7—20	7—12	4—38	7—28
G	10—24	10—11	13—2	10—6	10—10	13—10	11—10
H	10—10	6—8	10—28	12—8	10—33	13—12	10—23
I	10—1	10—9	10—23	10—10	10—28	10—22	10—15

Taking the average of six replications the cane yields with concentrated manures A, B, C and D are definitely greater than the control (+1 md. 11 srs., +1 md. 22 srs., +1 md. 3 srs. and +22 srs.) and greater than the plot F with heavy molasses dressing (direct application) (+3 mds. 38 srs., +4 mds. 9 srs., +3 mds. 35 srs. and +2 mds. 9 srs.). Plot F shows a definite depressant effect as compared with the control (—2 mds. 27 srs.). Castor cake treated plots show lower yields than concentrated manures.

TABLE XI

Calculations on the cane yield and total sucrose per acre—Co 312.

Treatments	Cane yield in 1/90th acre	Cane yield per acre	Sucrose per cent cane	Total sucrose per acre	Excess cane yield over control	Excess cane yield over F	Excess sugar yield over control	Excess sugar yield over F
	Mds.	Mds.		Mds.	Mds.	Mds.	Mds.	Mds.
A	11—26	1048·5	12·22	128·15	+104·75	+355·5	+17·70	+42·83
B	11—37	1073·25	11·09	118·96	+139·50	+380·25	+6·70	+33·60
C	11—23	1041·25	12·27	127·70	+107·50	+348·25	+16·30	+42·40
D	10—37	983·25	12·21	120·05	+49·50	+290·0	+8·62	+34·75
E	10—36	731·0	12·52	111·52	—200·0	+38·0	+0·09	+26·22
F	7—28	693·0	12·31	85·30	—240·75	...	—26·13	...
G	11—10	1012·5	11·62	117·65	+78·75	+319·5	+6·22	+32·35
H	10—23	951·75	10·56	100·50	+18·00	+258·75	+10·93	+15·20
I	10—15	933·75	12·47	111·43	...	+240·75	...	+26·13

The cane variety Co 312 of all the three varieties taken have responded most effectively to the concentrated manures. The depressant action of direct application of molasses has been evident not only in the case where molasses has been administered in heavy doses (treatment F) but also in the case of application in light doses (treatment E).

Taking the cane yield per acre while concentrated manure A, B, C, D treatments show an increase of 144·75, 139·5, 107·5 and 49·5 mds. respectively, molasses, direct application in light and heavy doses (treatments E and F), show a deficit of 200 mds. and 240·75 mds. respectively. It may be noted that castor cake in light and heavy doses (treatments G and H) do not respond so well as the concentrated manures (+78·75 and +18·0 mds. respectively over control). The excess of cane yield over F (plot heavily treated with molasses) with concentrates manures A, B, C, D are uniformly high (+385·5, +380·25, +348·25+290 mds. respectively). The castor cake plots G and H show an increase of 319·5 and 258·75 mds. while the control plot shows an increase of 240·75 mds. The plot receiving light dose of manure shows an increase of 38 maunds over F.

The increase in sugar yield per acre as compared with control in case of A, B, C and D are 17·7, 6·7, 16·3 and 8·62 mds. respectively, while E shows no increase (+0·09 mds.) and F indicates a deficit of 26·22 mds. Castor cake (G and H) treatments show an increase of 6·22 and 10·93 mds. respectively. The excess in sugar yield per acre over F in case of A, B, C and D are 42·83, 33·60, 42·4 and 32·74 mds., while castor cake (G and H) show an increase by 32·35 and 15·2 mds. respectively. Control indicates an increase of 26·13 mds. over F.

TABLE XII

Co 331, LATE-RIPENING VARIETY

Percentage of total sucrose in cane obtained under different manurial treatments (Tests carried out after verification of the maturity by top-bottom brix and purity ratios)

Treatments	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Average
A	11·12	11·14	11·49	10·64	11·74	11·20	11·22
B	11·36	9·71	11·39	11·47	10·99	11·31	11·04
C	11·67	10·29	12·11	11·42	12·16	12·26	11·65
D	11·44	10·45	11·90	11·02	11·44	11·65	11·32
E	11·89	10·76	11·88	11·09	11·44	12·58	11·61
F	11·11	8·99	11·22	11·59	9·66	11·38	10·66
G	11·00	10·73	11·53	11·40	11·67	11·12	11·24
H	11·29	10·53	11·38	11·41	12·29	10·78	11·28
I	11·10	10·35	11·71	11·23	11·01	12·1	11·25

In Co 331, a late-ripening variety, we find as we observed in other cases, the total sucrose in cane in all treatments tends to a maximum and is nearly the same irrespective of the manurial treatments. F, i.e. the plot receiving heavy molasses dressing, however, shows a definite decrease in sucrose content.

TABLE XIII

Yield of cane Co 331 per plot of 1/90th acre (Harvested on 1st March 1939)

Treatments	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Average of six replications
	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.	Mds. Srs.
A	9—5	10—7	8—20	9—7	8—15	8—2	8—36
B	8—28	9—30	10—8	8—37	8—31	9—28	9—14
C	9—7	8—15	9—21	10—5	8—28	9—15	9—29
D	8—37	8—36	7—36	7—20	10—33	9—1	8—34
E	9—3	10—0	9—10	11—18	9—6	9—30	9—31
F	6—38	7—27	7—5	8—38	6—28	6—12	7—10
G	8—30	9—1	9—30	9—26	9—0	9—12	9—11
H	7—30	10—10	9—30	8—26	9—11	9—26	9—9
I	8—32	9—30	8—20	9—8	9—2	9—18	9—5

TABLE XIV

Yield of cane and sucrose per acre and calculation of the excess of cane and sugar yields over control and F treatment

Treatments	Yield of cane per 1/90th acre	Yield of cane per acre	Sucrose per cent cane	Total sucrose per acre	Excess cane yield per acre over control	Excess cane yield per acre over F	Excess sugar yield per acre over control	Excess sugar yield per acre over F
	Mds.	Mds.		Mds.	Mds.	Mds.	Mds.	Mds.
A	8—36	801·0	11·22	89·98	—20·25	+146·25	—2·90	+20·19
B	9—14	841·5	11·04	101·51	+20·25	+186·75	+8·09	+31·72
C	9—29	875·25	11·65	101·96	+54·00	+220·50	+9·54	+32·17
D	8—34	796·5	11·32	90·16	—25·25	+141·75	—1·26	+20·39
E	9—31	879·75	11·61	106·5	+58·50	+225·00	+14·08	+36·71
F	7—11	654·75	10·66	69·79	—166·50	...	—22·63	...
G	9—10	832·5	11·24	93·57	+11·25	+177·75	+1·15	+23·78
H	9—9	880·25	11·28	99·29	+59·0	+225·50	+6·87	+29·50
I	9— 5	821·25	11·25	92·42	...	+165·50		+22·63

In the case of Co 331, a late-ripening variety, the cane yields with concentrated manures as compared with the control plots have shown significant results with B and C treatments, the performance in the case of A and B being negative. The anomaly in the results is due to better cane yields in the control plot. Castor cake treated plots (G and H) have given good result and so has E having light dressing of molasses. The most outstanding result, as has been observed also with other cane varieties, is the depressant action of molasses in heavy doses, where there is a deficit of 166·5 mds. in the cane yield.

Comparing with treatment F the yield of cane is uniformly high with concentrated manures (+146·25, + 186·25, + 220·50 and + 141·75 respectively). The performance in the case of castor cake treated plots is about the same as the prepared manures (+177·15 and 225·5 mds. respectively). The deleterious effect is not evident in case of light dressing of molasses, the increase in cane yield over control being quite high (+225 mds.). Even the cane yield in the control plot is greater than F by 165·5 mds.

The sugar yields are synchronous with the cane yields since the percentage of total sucrose is more or less the same irrespective of the manurial treatment.

Cane variety may be one of the factors determining the response to different manures. It may be said that whereas Co 313 and Co 312 respond quickly to the concentrated manures, it does not do so much with Co 313.

CONCLUSIONS

1. An easy biological process has been evolved for the conversion of fairly large quantity of exhaust cane molasses into a clean, dry inodorous manure with a high nitrogen content.

2. It requires installation of a small manure-making plant, as described in the paper in detail, requiring a few masonry tanks, centrifugal pumps, air blowers and leading pipes.

3. It was revealed that, whereas fermentation under acid condition without neutralization lead to loss of nitrogen, fermentation with intermittent addition of lime to neutralize the acidity gave definite evidence of nitrogen fixation being about twice the total nitrogen content in the original molasses.

4. It was found that the use of pure culture of yeast as started instead of mixed bacteria consisting of yeast, *B. coli*, acetic and lactic organisms gave sludge with higher nitrogen content than that obtained when mixed bacteria was used. The nitrogen fixation with molasses and filter press cake mixed in equal proportions using pure culture of yeast as starter gave nitrogen fixation about three times the total nitrogen present in the original molasses.

5. By a series of experiments taking a particular yeast variety where neutralization was effected with sodium carbonate solution instead of milk of lime it was found that heavy aeration led to about one-and-a-half times the yield obtained under normal conditions of fermentation. The use of am monium sulphate, and more significantly ammonium phosphate, to the extent of 1-5 per cent gave increased yeast yield (three times using ammonium sulphate and six times using ammonium phosphate). Higher yeast yields were obtained on fermenting at increasing dilutions, sp. gr. 1017 giving the highest yield.

6. Thus fermentation at the neutral point, i.e. under conditions where the acidity is constantly neutralized by milk of lime led to increased yield of yeast.

7. The biological process evolved gives product like yeast, calcium acetate, propionate, lactate, butyrate and also nitrogenous decomposition products, as indol and skatol acetic, propionic, butyric acids and their esters which are said to contain plant harmones are likely to be present. Thus whereas molasses has very little value as manure, its biological products contain valuable plant food. The biological process of conversion of molasses into manure augments the yield of yeast, calcium salts of organic acids and also the plant harmones described above. An investigation into the existence of the harmones by micro-methods is in progress. It is argued that fermentation with aeration and constant neutralization increases the yeast yield and diverts the course of fermentation so as to give the maximum production of yeast with least alcohol formation. The latter point is also being investigated.

8. Cropping tests were conducted with two manures prepared by the rapid process—molasses manure with intermittent addition of lime with aeration and molasses and filter press cake manure at the Kalyanpur Farm, United Provinces, in collaboration with the Agricultural Department. Working with three varieties of cane, Co 313, Co 312 and Co 331—early, medium and late ripening varieties—with six replications in randomised blocks indicate that molasses, when directly applied in the soil, had definite depressant effect as compared with the control in heavy doses, which increased with increased application although in smaller doses the effect was not very significant. In the case of Co 312, depressant effect was evident when molasses was applied both in light and heavy doses.

The concentrated manures gave definitely increased cane yields comparable with yields obtained by using castor cake as manure. The sucrose per cent in cane was slightly higher with concentrated manures than with

molasses. Taking a particular variety, Co 313, the yield of cane was approximately 100 mds. more per acre with the prepared manures as compared with the control, while molasses direct application gave 100 mds. cane less. There was an increase of about 20 mds. of sugar per acre with the new manures over the control, while there was a decrease in the yield of 20 mds. of sugar in case of direct molasses application.

9. Direct molasses application lead invariably to diminished percentage of germination and disease, such as yellowing of leaves, white ants, etc., while the prepared manures made canes less susceptible to such attacks.

10. The cost of production of the manures come to approximately 12 annas per maund giving a return of the cost of molasses to sugar factories at 4 annas.

11. Considering the relative efficiencies 20 mds. of molasses will have the same effect as 3 to 4 mds. of the concentrated manures.

Acknowledgements

My thanks are due to Mr. R. C. Srivastava, B.Sc., O.B.E., Director, Imperial Institute of Sugar Technology for his valuable advice and giving me the necessary facilities for carrying on the work.

I have particularly to thank Mr. P. B. Richards, I.A.S., Director of Agriculture, United Provinces, for taking a keen interest in the concentrated manures prepared by the biological process and placing at my disposal three acres of land and the necessary staff for arranging for the cropping trials at the Kalyanpur Farm, United Provinces. The name of Mr. Gajadhar Lal, B.Ag., Superintendent of the said farm is also to be particularly mentioned for careful planning of the plots and recording various details regarding cropping tests.

I have also to thank Mr. J. P. Shukla, M.Sc., my assistant for furnishing me with the harvesting data and analysis of cane samples and Mr. G. S. Datta, B.Sc., for preparing the manures and providing me with some data regarding nitrogen balance under various conditions of manufacture of manures.

REFERENCES

Bhaskaran, T. R. and Subramanyan, V. (1937). *Proc. Sugar Tech. Assoc. India, Sixth Convention*, p. 424-32

Desai, S. V. and Fazul-ud-Din (1938). *Ind. J. Agric. Sci.* **8**, 38

Gainy (1923). *J. Agric. Res.* **24**, 289-96

Kogl (1937). *Nature* **140**, No. 3544

Narayana (1932). *Symposium on the Role of Organic Matter in Soil. Soc. of Biol. Chemist India*, p. 14

————(1937). *Proc. Sugar Tech. Assoc.*

Paramanik, B. N., Rao, R. B. and Lal, J. B. (1937). *Proc. Sugar Tech. Assoc. India, Sixth Convention*, p. 188-96

Sen, H. D. (1938). *Indus. Ind.*, p. 250-1

Sen, H. D. and Dutta, G. S. (1937). *Proc. Sugar Tech. Assoc. Sixth Convention*, p. 333-43

————————(1938). *J. Sci. & Tech. Ind.* **4** (1 and 2), 59-63

Tinkler (1937). *Nature* **140**, No. 3544

Viswanath and Suranarayana (1932). *Symposium on the Role of Organic Matter in Soil. Soc. Biol. Chem., India.*, p. 8

A REVIEW OF THE APPLICATION OF STATISTICAL THEORY TO AGRICULTURAL FIELD EXPERIMENTS IN INDIA*

BY

P. C. MAHALANOBIS

Statistical Laboratory, Presidency College, Calcutta

I. General review of the present position

A REVIEW of the application of statistical theory to agricultural field trials in India in recent years is largely a story of the triumph of methods devised by R. A. Fisher at the Rothamsted Experimental Station. The new developments also bear remarkable testimony to the scientific vision of Sir John Russell, Director of the Rothamsted Experimental Station, who had recognized as early as 1919 the need of the application of statistical theory to agricultural research, and had not only persuaded Fisher to take up this subject but had given him full scope and freedom for working out appropriate statistical methods in his own way.

The basic principles of the new method are now well known and need not be discussed in detail. In order to appreciate the revolutionary advance brought about by the introduction of the new technique, let us however consider for a moment the contrast between experiments of the old and new type.

The old type of field experiment

Suppose we wish to compare the yield of say six varieties or the effect on yield of six kinds of manures. In the old type of experiment the field would be divided into six plots, and a single plot would be allotted to each treatment. As Fisher [1935] explains 'the treatment giving the highest yield would of course appear to be best, but no one could say whether the plot would not in fact have yielded as well under some or all of the other treatments'. It is known that within the same field wide differences exist in the fertility of the soil. Even when the soil fertility is uniform, there are innumerable other causes which affect the yield. How can we be sure that the observed differences in yield are due to the difference in the treatments, and not to soil heterogeneity? How can we be sure that they are not due to chance fluctuations? This is the basic problem. In order to solve it we must eliminate the effect of soil heterogeneity, and make an unbiased estimate of the magnitude of errors due to chance so that we may be sure that the observed effect is significant in comparison with the size of such chance errors.

The Fisherian technique

Let us now see how Fisher solved the problem. Consider the same experimental field which had been originally divided into six portions.

* Presented before the meeting of the Board of Agriculture and Animal Husbandry in India held in Lahore in December 1937

Fisher simply further sub-divided each portion* into a number of plots of smaller size ; and within each portion (or block as he called it) he assigned one plot to each treatment but strictly in a random manner. We have now the randomized block in its modern form. Using the principle of block division in two directions symmetrically we get the well-known Latin square.

Results governed by laws of chance

The important point to be noticed is that the results will be now governed entirely by the laws of chance. There are innumerable causes which produce differences between the plots, and we know from the conditions of the experiment that it is impossible in practice to secure that the plots will be all alike. But the validity of the estimate of error is now guaranteed by the process of randomization, namely ' the provision that any two plots, not in the same block, shall have the same probability of being treated alike, and the same probability of being treated differently in each of the ways in which this is possible' [Fisher, 1935]. The calculus of probability and the apparatus of the statistical theory of sampling distribution can now be used with complete confidence. The logical foundations of scientific inference were thus made secure, and agricultural experiments were placed for the first time on the same footing as experiments in other sciences. In actual fact the statistical theory of exact distribution in terms only of actual observations, popularly known as distributions in ' Studentized form ', achieved a good deal more. It made possible general conclusions being drawn with logical rigour from particular observations. But this is a topic of statistical rather than agricultural interest and must be passed over here.

Elimination of soil differences

The second point to be observed is that by the technique of block division the problem of soil heterogeneity was solved at the same time. As each block contains all the treatments once and once only, differences between the total yields of the different blocks could safely be ascribed, apart from errors of sampling, to soil differences ; and could be eliminated by suitable statistical methods. This of course led to a great improvement in the precision of the comparisons. When we remember that in particular experiments in India as much as 90 per cent of the total variation is sometimes caused by soil differences, the importance of eliminating its effect will be easily appreciated.

The analysis of variance

The third point to be emphasized is the close connexion between the field procedure and the procedure of statistical analysis in the Fisherian technique. In fact they are merely two aspects of the same problem ; and to quote Fisher [1933] ' once the practical field procedure was fixed, only a single method of statistical analysis could be valid. . . The specification of the particular process of randomization carried out, determined in advance the correct statistical analysis of the results '.

*I need scarcely add that the experimental field may be divided into any number of convenient portions each of which is further sub-divided into a number of plots.

To sum up then, replication, randomization, and block division (or local control) were the principles of design introduced by Fisher [1923] at Rothamsted. Replication is essential because it is the sole source of the estimate of error, while randomization is necessary to guarantee the validity of the estimate, i.e. to ensure that the estimate will be unbiased. The purpose of block division is to increase the precision of the comparisons by elimination of soil differences, while replication is also useful in securing the same object by diminishing the experimental error. Finally the analysis of variance* gives a convenient and valid method of extracting the information contained in the observations. As Wishart has pointed out, the Fisherian technique 'was something in the nature of a revolution,' and altered the subsequent course of agricultural experiments throughout the world.

Previous conditions in India

It took some time before the new technique was introduced into this country. Seven or eight years ago in India the control used to be almost always repeated, but the treatments were usually laid down without replication. Even when replication was used, it was of the systematic type and inadequate in number. In interpreting the results, the usual practice was to compare the means of the various treatments. In a few cases probable errors of means were calculated. The ordinary formula in the classical theory of errors was used for this purpose. This was inexact for the twofold reason that the observed variance was substituted for the corresponding population value, and the effect of using small samples was ignored.† Besides in the absence of randomization, such estimates were not unbiased, and could not be validly used for purposes of comparisons. Finally there was no attempt to eliminate the effect of soil differences. It is no wonder therefore that many of the inferences drawn from the old experiments were unreliable. Even when the results were true, this could not be asserted with scientific precision. A fair idea of these old-type experiments, which used to be conducted in India a few years back, can be obtained from 'Analysis of Manurial Experiments in India' by Vaidyanathan [1934].

Introduction of the new technique in India

Like most other recent movements in agriculture in India, we owe the introduction of statistical methods to the Royal Commission on Agriculture (report, pages 617-8), which had made definite recommendations on this point in 1928. In actual practice the modern period of field experiments began in India, I believe, with the foundation of the Imperial Council of Agricultural Research in 1929 on the recommendation of the Royal Commission.

* See note on 'variance', 'standard error', 'covariance', etc. (Appendix II)

† It is of some personal interest to me to recall here that to this particular problem I owe my contact with agricultural work. In 1924 my attention was drawn by Dr. W. Burns (Agricultural Commissioner with the Government of India), then working in Bombay, to an experiment in which six varieties of rice were laid out in ten replicates systematically arranged side by side in long stripes. On the assumption of a systematic variation in soil fertility, it was possible to eliminate the soil differences by graduation, and it was found that the precision of the comparisons could be considerably increased. At that time I was quite unfamiliar with the Rothamsted work, but Dr. Burns' problem soon made me get acquainted with the Fisherian method, and made me realize its great value.

The earliest experiment of the new type, a varietal trial on rice with a 12 × 12 Latin square was reported in the *Indian Journal of Agricultural Science* in 1931. The Imperial Council of Agricultural Research from its inception laid emphasis on statistical methods, created a statistical section at headquarters with a whole-time statistician at its head, and gave a grant to the Statistical Laboratory, Calcutta, for advanced studies and researches in statistics. In fact I believe it was soon made a condition of all Imperial Council of Agricultural Research schemes that the experimental designs should be of the approved type. The Statistician to the Imperial Council of Agricultural Research gives his advice on all standard schemes in the province, and personally visits a large number of farms every year. Help is also available, especially on the research side, from the Calcutta Statistical Laboratory. In the course of this work a series of 'Statistical Notes for Agricultural Workers' was started of which 24 numbers have been published so far. In 1932 arrangements were made in Calcutta for giving special courses of instruction in statistical methods to officers who were sent there on deputation for this purpose. During the last five years such training has been given to over 75 agricultural officers from all over India, which, I believe, has helped materially in raising the general standard of work. The lead given by the Imperial Council of Agricultural Research in all these ways has resulted in the Latin square and randomized block designs being used with great success all over India. It is probably no exaggeration to say that no important experiment in India is now laid out on an old type design. This must be considered to be a solid achievement.

Factorial (complex) experiments

We may now consider some further developments of the new techniques. As early as 1926 Fisher had advocated the use of factorial designs in which two or more types of treatments were laid out on the same field.

Suppose we wish to compare three varieties, and the effect of three manurial treatments on each of these varieties. If we conduct the experiments separately, and use six replications, we shall require for the varietal trial $3 \times 6 = 18$ plots. For the manurial portion we shall require three experiments, dealing respectively with the three varieties. With six replications we shall therefore require 54 plots for the manurial investigations and 18 plots for the varietal comparison or 72 plots altogether.

Instead of simple experiments, suppose we combine them in one factorial (or complex) design. First of all, for nine combinations (3 varieties × 3 manures) we can then afford to give eight (instead of six) replications each in the same field of 72 plots. Secondly, we shall have no less than 24 replications available for the varietal or manurial comparisons; so that, if the standard error per plot remains the same, the accuracy of the main comparisons will be increased four times. Finally, the three manurial treatments cannot be directly compared in the separate experiments; but in the factorial design the comparisons would be completely valid. In other words, the differential manurial requirement of particular varieties, i.e. the interaction between varieties and manures, if any, can be investigated only if the experiment is designed in the factorial form. With three or four factors the amount of information obtained is proportionately even greater. Besides the main effects,

we can not only study the differential effect (or interaction) of the factors two by two, but also the response of one factor in the presence or absence of two or more of the other factors.

A factorial experiment is thus not only more efficient in the sense that with the same number of plots all the factors can be studied with greater precision, but is also more comprehensive and will give information about differential response which could not possibly have been obtained by any number of experiments of the simple type. This is why Fisher [1926] definitely rejected the orthodox principle of varying the factors only one at a time and said : 'No aphorism is more frequently repeated in connexion with field trials than that we must ask Nature few questions, or ideally, one question at a time. The writer is convinced that this view is wholly mistaken. Nature, he suggests, will best respond to a logical and carefully thought out questionnaire ; indeed, if we ask her a single question, she will often refuse to answer until some other topic is answered.'

Before leaving this topic it is perhaps worth while pointing out a third advantage of the factorial design. In the orthodox method all the factors except one are deliberately kept approximately constant. In the result, information is obtained only for a narrow range of controlled conditions. In the factorial design on the other hand a number of factors are allowed to vary at the same time, so that conclusions drawn from such an experiment have a much wider basis for induction.

In India the first factorial experiment with three varieties of potato under three manurial treatments was laid down at the instance of the Statistical Laboratory at the Visvabharati Institute of Rural Reconstruction at Sriniketan in 1931. During the last four or five years similar two-factor experiments have become quite common all over India. Designs with three or four factors are also being used with success. As an example I may mention the four-factor cultivation experiment with rice (three varieties, five dates of planting, three spacings, and three numbers of seedlings per hole) designed at the Statistical Laboratory and conducted under the Imperial Council of Agricultural Research rice research scheme at Chinsurah for the four seasons 1933-37. The summary of results shown in Appendix I will give some idea of the wealth of information which can be obtained only from designs of this type.

In spite of their efficiency and comprehensiveness certain objections have been raised against the use of factorial designs which may be briefly considered here. It has been pointed out that the main effects are obtained with greater precision than the interactions ; also that the experiment includes many combinations which are never likely to be used in practice. This is quite true but inevitable. When we have no knowledge as to what particular combinations are likely to be useful, it is desirable that we should seek to survey the whole range of all the factors. But an extensive field of survey inevitably implies a lower level of accuracy. However as experience is gathered, the field of enquiry can be narrowed by reducing the number of combinations, with an automatic increase in the precision.

A second objection is more serious. With an increase in the number of combinations, the size of the block becomes too large for adequate elimination of soil-heterogeneity with consequent increase in the residual error. The

difficulty has been admirably got over recently by the 'splitting of plots' and the 'confounding of interactions'.

Split-plot and 'confounded' designs

In the factorial design complete information about all the combinations can be obtained at the cost of accuracy. We can, however, increase the precision by sacrificing a portion of the information. This is just what is achieved in the 'confounded' design. The whole array of treatment combinations is therefore not included in the same block, but deliberately distributed over two or more balanced sub-blocks. Experience has shown that high-order interactions are often insignificant, or even when statistically significant are not of much practical importance. In the confounded design information about such high-order interactions is usually sacrificed to increase the precision of other comparisons. If we like we can, however, arrange to obtain some information about all the interactions, but inevitably at a lower level of precision, by 'partial confounding'.

The split-plot lay-out is a simple example of confounding in which the main effects of one of the factors are confounded. This design is particularly useful when some of the treatments are such that they cannot be conveniently applied to small plots. These main treatments are therefore laid out in a randomized block or Latin square design, but each whole-plot is divided into a number of sub-plots which are allotted at random to the different sub-treatments. The residual variance between sub-plots gives the appropriate error for the comparison of sub-treatments, while the residual variance between plots gives the error for the whole-plot treatments.

The split-plot design is being extensively used in India, but the confounded design has so far not attracted much notice.* As far as I know, one elegant design prepared by Yates has been laid down at the Tocklai Tea Experimental Station, and one design has been supplied by the Statistical Laboratory to the Dacca University for the Imperial Council of Agricultural Research scheme.

The designing of confounded lay-outs is an interesting exercise, and in skilled hands it has attained a high degree of efficiency. I would draw the attention of all agricultural workers interested in this subject to the discussion by Fisher [1935], Yates [1937] and that in the *Rothamsted Reports* for the last few years.

Complete factorial designs, as we have seen, are both efficient and comprehensive. But they need great care at every stage of the work, and with a large number of factors require blocks which are inconveniently large in practice. There is, therefore, a limit to the usefulness of this type of design depending on the heterogeneity of the land, the number of factors and nature of the problem, the skill and experience of the investigator, etc. The split-plot design is very convenient in problems in which knowledge about the main treatments is already available. But I am of opinion that it is the confounded design which has the greatest possibilities in India, both on account of its flexibility as well as its economy of cost. Caution is needed, however, both

* This review was originally written in December 1937. Since then the principle of confounding is being increasingly used in India.

in designing the experiment and in carrying out the statistical analysis. In the beginning, therefore, it will be desirable to use standard patterns under the guidance of statistical workers.

Interpretation of results

Before leaving this subject I would like to add a few words in regard to the interpretation of the results. I have found that many agricultural workers are able to reduce the data correctly and complete the arithmetical part of the analysis of variance without, however, being able to draw the necessary inferences. 'Significance' and 'non-significance' are purely technical terms with the exact implication of which every experimenter should be familiar.

Suppose we are working on the five per cent level of significance. Then the rule is that any effect which is likely to occur by pure chance less than once in twenty times on an average will be called 'significant'. On the other hand, effects which are likely to occur more frequently than once in twenty trials will be called 'non-significant'. Let us see the application of this rule in a concrete case. Suppose we have an experiment in which the treatments do not in fact produce any effect. Even then, with the present rule, the effect will appear to be significant about once in twenty trials, and in the remaining 95 per cent of cases we shall quite correctly decide the effect to be nil. The risk of considering an effect to be real, when in fact it does not exist is thus limited to just five per cent. Similarly working at one per cent level of significance, we limit the risk of our accepting a spurious effect as real to one per cent. In other words we work with odds of 99 to 1 in our favour.

I may point out at this stage a peculiar property of statistical inference. Suppose we are working on five per cent level. We have seen that even when the effect is nil, we shall judge it to be real once in 20 trials. In other words, if statistical theory is right, we must be wrong in our judgment in five per cent of the cases. The possibility, or rather, the certainty of error is thus inherent in the structure of statistical inference. This knowledge is a salutary check against an exaggerated sense of our own infallibility.

The experimenter must, therefore, be careful in attaching undue importance to an isolated result which may appear to be statistically significant and yet does not fit in with general agricultural experience. Such results should not be ignored, but should neither be accepted until corroborated by further experiments. On the other hand, results statistically insignificant should not be always neglected. If they appear to be plausible from other considerations, further investigations should be made with increased precision of comparison.

In short, the experimenter must use his critical judgment and discretion in the final interpretation of the results. Statistics is both indispensable and invaluable, but it cannot replace the human mind.

Precision of Indian experiments

Having reviewed the broader features of the new technique, it will be of some interest to examine the precision attained in Indian experiments. I am sorry, in the limited time at my disposal, I was unable to collect relevant information from the different provinces of India. I shall, therefore, discuss

this point with the help of materials from Bengal and Assam which were readily available in our Laboratory.

The average standard errors per plot (expressed as percentages of mean yields) for four or five careful series of varietal trials with *aus* and *aman* rice at Chinsurah Farm during the five seasons 1932-33 to 1936-37 are shown below. (The figures within brackets give the number of experiments on which the average is based.)

Bengal: Chinsurah Farm varietal tests

(Standard error per plot as percentage of mean)

Year.	Rice crop	
	Aus	*Aman*
1932-33	11·61 (3)	10·10 (5)
1933-34	9·68 (2)	10·06 (5)
1934-35	8·38 (3)	10·21 (6)
1935-36	..	19·10 (5)
1936-37	9·19 (2)	9·74 (5)

Similar figures for recent rice and sugarcane experiments in Assam for the period 1932-33 to 1935-36 are given below.

Assam

(Standard error per plot as percentage of mean)

Centre	Crop	Variety	Manure	Complex
Karimganj	Rice	6·78 (24)	8·00 (4)	8·25 (6)
Titabar	Rice	10·50 (20)	7·98 (4)	..
Jorhat	Sugarcane	8·21 (9)	7·71 (7)	15·40 (4)

It will be noticed that in Bengal and Assam in the case of rice and sugarcane, a standard error of 8 or 10 per cent per plot is quite usual.

Comparative figures for English experiments are quoted below from the Report of the Rothamsted Experimental Station for 1935.

English stations

Crop	Latin square	Randomized block	All arrangements
Potato	6·8	9·2	..
Sugarbeet	6·1	7·9	..
Swedes	..	..	6·9
Mangolds	..	..	8·2
Kale	..	..	7·7

Wishart and Sanders [1936], are of opinion that a standard error of 5 per cent for root crops and of 10 per cent for cereals may be considered satisfactory. Judged by English standards, the work in Assam and Bengal is therefore not unsatisfactory. I have no reason to think that careful work in other parts of India is in any way less accurate.

Latin square v. *randomized block*

Owing to the possibility of eliminating soil differences in two directions, one would expect the Latin square to be more accurate than the randomized block, and English experience has generally borne this out. I am not in possession of enough data to judge the position in India. My general impression is that the Latin square has been given preference here in small-scale varietal work. For large-scale work, I think on the whole the randomized block has been used more extensively in India, no doubt on account of its greater flexibility. One advantage of the randomized block is that an estimate of error can be calculated separately for each comparison. Yates [1935] has pointed out that 'this is of great value when handling new and unknown material, or treatments which may produce large differences and even partial or complete failures. In such cases the assumption of constancy of error variance is entirely unjustified, but in a randomized block experiment any treatment or treatments may be excluded and the analysis carried out on the remainder. This is not true of either the Latin square or of confounded arrangements'.

Complex or factorial designs in India apparently have a slightly higher standard error per plot (of the order of 10 or 15 per cent of mean yield) than the simple Latin square or randomized block. This is probably due to the experimental difficulties in managing more than one set of factors on the same plot and to large block sizes.

Uniformity trials

In a randomized block design the greater the homogeneity of plots within blocks the greater the accuracy of the experiment. In practice this can be secured experimentally only to a limited extent. But sometimes it is possible to increase the precision of comparison very considerably by suitable statistical adjustments. Suppose, for example, that the initial fertility of plots is known from a previous uniformity trial in which the same variety is planted on all the plots and given the same manuring, and the relative fertility of individual plots remains fairly stable; then the yields in a succeeding year will be appreciably correlated with the yields in the uniformity trial. In this situation it is possible, with the help of the analysis of covariance, to make allowances for the initial differences in fertility among plots within each block. The use of such adjusted yields can then be used for the final comparison. This method has been sometimes known to have increased the precision even ten or twelve times.

It should not be imagined, however, that this is always or even generally possible. In fact with annual crops the fluctuations in fertility of the same plot from year to year are usually so great that the increase in precision obtained by this method is not in general commensurate with the expense or the delay of one season involved in a uniformity trial.

It is therefore usually unprofitable to conduct a uniformity trial as a preliminary to the main experiment with a view to increasing its precision. Repeating the actual experiment twice would most often give more information. This is why we have for a long time discouraged the adoption of a uniformity trial as a routine practice. It may be noted, however, that there are special circumstances in which such trials may be very useful indeed, for example, in the case of horticultural experiments.

Size and shape of plots

We may now consider the question of size and shape of plots. As early as 1910, Hall harvested a wheat and a mangold field in small units, and found that the variation between plots was appreciably reduced until the size reached was about 1/40 acre. It was therefore concluded, and the conclusion was corroborated by other uniformity trials, that the optimum size in England was somewhere about plots of 1/40 acre.

We have had occasion to examine the results of a number of uniformity trials in India, and we found that for varietal trials in many cases the plot could be reduced, so far as precision is concerned, to a very small size of the order of 1/140 acre. Plots of size 1/80 acre or 1/40 acre also give quite good results and can be safely recommended for convenience of agricultural operations. Given the area, the question of shape or orientation comes in. Christidis [1931] showed from theoretical considerations as well as experimental data that long plots placed parallel to the fertility gradient gave the best results. Our experience in India is also more or less similar. Sugarcane experiments at Pusa and other places in North Bihar show that strips, the length of which is 10 or 15 times greater than the width, give more accurate results. Rice experiments show the same tendency but to a smaller extent.

Size of blocks

The final precision of an experiment does not depend only on the best selection of plot size. What is needed is a choice of the optimum combination of the size of both blocks and plots. The best results will be obtained when the blocks are fairly homogeneous, (i.e. all the plots within the same block have nearly the same fertility), but differ appreciably as a whole between themselves. It is obviously not possible to give any limits for the block size. If the soil is fairly uniform, it is possible to work with blocks of a large size; on the other hand, if the fertility gradients are steep, the size of the blocks must be kept small. I had the opportunity of studying in detail the variation in soil fertility of a field of about one acre under rice at the Chinsurah Farm, which was harvested at my request in 7040 units of 9 inches by 90 inches (1/7744 acre). We tried many combinations of block and plot sizes, and found that a low standard error of about 3·5 per cent of mean yield per plot was obtained with a block size of 80 ft. × 44 ft. (about 1/12 acre) with 8 plots each of size 20 ft. × 22 ft. (1/100 acre). But considerably larger size of blocks 160 ft. × 44 ft. (or about 1/6 acre), or 160 ft. × 88 ft. (1/3 acre) with 8 or 16 plots each could be used with only a moderate increase in the error to about 5 per cent of mean yield per plot.

Success of the new technique

From the brief review given above, I think it can be stated without hesitation that in India wherever the Fisherian technique has been used on proper lines in field trials, it has been found entirely satisfactory in every way and has given excellent results. The working procedure is very flexible so that it can be adapted to suit the most diverse problems and conditions of work.

A good deal of valuable information regarding soil differences and the relative accuracy of different types of experimental designs is also fast accumulating in India. It is desirable in designing a new experiment that each experimenter should utilize all available information relating to his own work. In this way he would be often able to get a good idea of the type of design likely to give the best results, and also to safeguard himself against too large a margin of error by using an adequate number of replications or other methods of controlling soil differences.

Concomitant variations and correlational analysis

I have already considered the use of uniformity trials, and I may now briefly refer to certain other methods of increasing the precision of field trials by using concomitant measurements and the analysis of covariance. The underlying principle is simple. In a field trial there are many other factors besides yield which can be studied, and it often happens that some of these factors are correlated with the yield in the sense that variations in such factors cause (or are associated with) variations in the yield. It then becomes possible to separate and eliminate that portion of the variation in the yield which may be ascribed to these factors. In this way the precision of the experiment can be often increased very considerably. For example, it may happen in a field trial that the yields of different plots are disturbed by variations in the number of plants which have established themselves. When such disturbances are due to causes which have no connexion with the treatments under trial, it is clear that there can be no objection to making allowances for such variations. In the present example, by counting the number of plants in the different plots we can easily eliminate the variations in yield due to variations in plant number, and hence increase the precision of the experiment.

Similar methods may be used for eliminating the influence of varying intensity of attacks of pests and insects in different plots. It would be most undesirable to reject some of the yields simply because they appear to be too low. As Wishart and Sanders [1936] have remarked, ' once a start is made in rejecting actual figures, there is no knowing where to stop . . . . a little skill in the game will lead to very significant, but quite untrustworthy results. There is no wish to impugn the reader's honesty, but no man is so virtuous that he can afford to treat temptation with disdain '. The position would be quite different if some observations were recorded on the intensity of the insect attack in the different plots before the crop is harvested. Such records can then be used for making adjustments without bias.

The method of correlation or analysis of covariance can also be used with great advantage in other ways. If records of growth of the plant (height,

girth, tillering, etc.), are kept at different stages, such records can be correlated with the final yield, and may be utilized to furnish valuable information on many points. These methods deserve greater attention than they have received so far in India.

Missing yields of plots

Before leaving the subject of field trials I may refer briefly to another question which occasionally arises in practice. Owing to accidents or negligence on the part of the subordinate staff, it sometimes happens that the yields of one or more plots are missing or get mixed up. In such cases it is often possible to reconstruct approximately the missing yields by purely statistical methods, and thus recover much of the information which would have been otherwise thrown away. Formulæ for certain simple cases were given for this purpose originally by Allan and Wishart [1930] and a general solution was subsequently given by Yates [1933]. Additions to the theory have been made in the Statistical Laboratory and have been used with success for certain types of mistakes which had actually occurred in India. It cannot, however, be emphasized too much that such procedures are at best make-shift arrangements, and the damage done by careless work cannot be repaired by such methods. In any case these methods must be used with very great caution.

Use of random samples

The use of concomitant measurements usually involves a great deal of labour, which can be often reduced very considerably by adopting the method of random sampling. Consider an ordinary field trial. Suppose for any reason, such as shortage of labour or inclement weather or some other difficulty, it is found impracticable to measure the complete yield of each plot. In this situation we may take one or more random samples from each plot and measure the yield of these samples. Or consider the measurement of the height of plants at different stages of growth in the case of a field trial. For ordinary crops the number of individual plants in each plot is very large, and it is practically impossible to measure separately every plant in each plot. We may here take a random sample of the same number of plants in each plot, and measure only those plants which are included in these random samples. Sometimes complete enumeration is not only impracticable but even theoretically impossible. For example, if the dry weight of plants is sought to be studied at different stages of growth under different treatments, it is obvious that necessary measurements cannot possibly be carried on the same plants, but only on portions of the material under observation. In such situations there is no alternative but to have recourse to random sampling.

Fortunately, when used judiciously, this method is quite efficient, and the additional error introduced by this method is usually small. Thus, for instance, when the yields in a field trial are obtained by random sampling, the effective error variance will be simply the sum of the variance between plots and the variance, due to sampling. The latter being considerably smaller than the former, the increase in the variance will consequently be

small. The method of random sampling* has great possiblities which should be more fully explored in India.

Other applications of statistical theory

I have considered field trials at some length as this is the main topic for discussion. But statistical methods have also been used with success in other types of work in this country some of which may be briefly mentioned at this stage.

The principle of randomized replication has been used in pot culture, animal nutrition studies, experiments on incidence of pests, horticultural experiments, etc. Very recently it has also been used in sylvicultural experiments at the Forest Research Institute at Dehra Dun.

Correlational analysis has been used in a number of investigations on the influence of rainfall and other weather conditions on crop out-turn, and although valuable results have been obtained, the scope of such studies has been unfortunately much restricted in India by the paucity of reliable crop data extending over a large number of years. A good deal of valuable work is being done, chiefly under the auspices of the Meteorological Department, in agricultural meteorology in which statistical methods are being used extensively. Modern statistical methods are being increasingly applied in linkage and genetic studies at the Indore Institute of Plant Industry and elsewhere.

More advanced statistical technique has been occasionally used for the investigation of special problems, such as detailed studies of frequency distributions of cotton fibre in the Cotton Technological Laboratory at Matunga ; the use of composite tests of significance in plant physiological work ; the use of quantitative measures of group divergence for the scientific classification of varieties, etc. In the limited times at our disposal it will not be possible to discuss with profit such recent developments in detail.

On the whole, it may be said that agricultural workers in India have shown great readiness in using statistical methods, and have fully responded to the lead given by the Imperial Council of Agricultural Research in this matter. Given necessary guidance and facilities, there is every reason to hope that the use of such methods will steadily extend in India.

II. The future programme

Problems of special importance to India

We may now consider the future programme. It was only natural that in the pioneer stage, much of the work in India followed closely the agricultural practice at Rothamsted and other English stations. But with the valuable background of experience gained during the last six or seven years, and with

* To be quite pedantic it should be called ' random sampling from random samples '. For, all statistical work is necessarily based on random samples. The plot yields in a field trial, for example, are considered to be random samples from the hypothetical population of similar yields from the same plots under similar treatments in similar circumstances. Complete enumeration here merely means measurement of complete yields of all the plots which together constitute one single random sample. In the method of ' random samples ', smaller random samples are taken from the plots.

the better organization of statistics in India, the time has come for using statistical theory and developing suitable methods for the study of problems of special interest to our country. A few suggestions in this connexion may be useful as a basis for discussion.

Rainfall and irrigation in relation to agriculture

We are all familiar with the essential facts. Agriculture is the basic occupation, and the prosperity of trade, commerce, and industry are more dependent on it in India than in most countries of the world. The seasonal rainfall is concentrated within a comparatively short period, but fluctuates widely both in total amount as well as in distribution from year to year. A good monsoon with well-distributed rain usually means good crops and general prosperity, while a bad monsoon still causes, over a vast area, failure of crops and widespread distress.

Water conservation, irrigation, and drainage naturally constitute a subject of overwhelming importance, and I hope to be excused if I dwell at some length on this question. I have had the opportunity of studying in some detail the problem of rainfall and floods in Bengal and in Orissa. This has made me realize how great is its direct and indirect bearing on agriculture. In most parts of India, we have enough rainfall to produce sufficient foodstuff for our present population. Our real problem is to conserve the water, prevent waste, distribute the available supply in the most efficient way over different areas and at different times according to agricultural requirements for the production of the optimum crop, and finally to drain away the excess without causing any mischief. Viewed in this way irrigation, drainage, flood control, and agriculture are merely different aspects of the same fundamental problem.

We possess fairly satisfactory data about rainfall, owing to the activities of an efficient Meteorological Department. We also have some, though neither enough nor quite reliable, data relating to rivers. But unfortunately the chief gap is in the agricultural knowledge.

Let me give a concrete example. I had occasion recently to examine a large irrigation scheme in Bengal which had the dual purpose of supplying water for crops at times of deficient rainfall, and of flood flushing the area as an anti-malarial measure. The future health, prosperity, and happiness of one million people depended on the success or failure of the scheme. We could estimate from past records with reasonable accuracy what deficiencies in rainfall were to be expected in future. We could also calculate how much water could be supplied from the Damodar river at different parts of the season. But unfortunately the agriculturists were quite unable to supply reliable information regarding the optimum water requirement of paddy. It was not possible therefore to make any estimate with confidence of the increased yield which might be reasonably expected with irrigation from the available supply. And yet this was the critical factor on which everything hinged. If the increase in production was sufficiently large the scheme would succeed; otherwise it would fail. The effect of a wrong decision either way would be disastrous. If the scheme were abandoned when in fact it might have succeeded, a great opportunity would be lost. If it were proceeded with but failed, such failure would jeopardize for at least one generation the initiation of other

schemes even when the prospects of success were great. I had to make the best of a bad job, and tried to get round the difficulty by using statistical methods in a rather speculative fashion.

But that is a different story. To come back to our topic, we need then careful studies of the influence of rainfall and other climatic factors on crops. Such studies would be useful in two ways. First, for supplying badly needed information about the water requirement of crops. Secondly, for purposes of forecasting ; even when a failure of crops cannot be prevented, early information may often enable ameliorative action being taken in time.

Permanent climatic series

It will be desirable therefore to start well-designed experiments in different parts of the country for studying the influence of rainfall and weather conditions on the yield of standard varieties of crops. The experiments will be definitely of the long-range type, and will be continued for many years. Arrangements will also be made for recording a number of carefully selected meteorological elements. In planning this series, the needs of the country as a whole will be naturally kept in mind, and the work will be standardized sufficiently to enable valid comparisons being made between results obtained at different stations.

Phenological observations

The question of starting systematic phenological observations (such as earliest and latest dates of flowering of well-known plants, passage of migratory birds, advent of seasonal pests and insects, etc.), may also be given careful consideration in the same connexion. Such observations are likely to prove useful in many ways, not only in the study of seasonal variations of the weather, but in the control of pests and blights, and in throwing light on the behaviour of plants to environmental conditions.

Irrigation experiments

Well-designed experiments will also have to be laid down for the direct study of water requirement and the growth of crops under irrigation. In the first stage it will probably be desirable to conduct such experiments under conditions in which both the supply and the drainage of water can be controlled at desired levels. As experience is gathered, it will no doubt be possible to approximate more closely to field conditions.

In certain parts of India waterlogging and floods are often of almost as great importance as the lack of water. Carefully designed experiments are therefore needed for studying questions of seepage, waterlogging, etc., under actual agricultural conditions.

Soil erosion is a problem of importance in many regions. This question is closely connected with run-off and drainage, and requires to be studied in relation to irrigation. The possibilities of using agricultural methods, such as planting of suitable crops of trees for controlling soil erosion, deserve investigation in the same connexion.

All these irrigation experiments, to give the best results, require the active cooperation of the engineer and the agriculturist ; while the scope of using statistical methods is practically unlimited.

Soil studies

Another problem of great importance is the study of the soil, and of the changes in its condition, in different parts of the country. As regards progressive deterioration, the Royal Commission on Agriculture [1928] was of opinion : ' While paucity of records of crop out-turn throughout India over any long period of time makes the matter impossible of exact proof, we are of opinion that the strong presumption is that an overwhelming proportion of original lands of India long ago reached the condition to which experimental data point'.

Permanent manurials

Careful experiments are needed to study whether soil deterioration is still progressing, and if so at what rate, and also to study the influence of different types of manures to prevent such deterioration and maintain the soil in a healthy condition. The time has therefore come to lay down a series of permanent manurials on modern lines at a number of selected stations. Where practicable, the manurial series may be suitably combined with advantage with the climatic series.

Multiple experiments

Multiple experiments offer great advantages for the study of climatic, varietal, manurial, and other questions. In this plan a number of experiments of the same type would be laid down with the same or similar groups of varieties or treatments in different parts of the country. Owing to the large differences in soil and climatic factors, not only between different provinces but even in different districts of the same province, these experiments would be conducted under widely varying conditions.

The work will have to be planned as a whole. When the same set of varieties or manures or other treatments cannot be used in all the experiments of a given series, it should be still possible to link up the work by providing overlapping treatments through which comparisons can be made with confidence. Standardization will obviously be necessary, but sufficient flexibility must be retained to adapt the work to suit local needs.

If the multiple series is designed as a whole, it will be often possible to conduct a joint analysis of the results, and to study the influence of the variations in the different factors. In this way valuable information might be obtained in a few years which would otherwise take a very long time to collect. In 1931 I had pointed out the need and scope of such multiple experiments under Indian conditions and had pleaded for their adoption at the joint session of the Agriculture, Physics and Mathematics sections of the Indian Science Congress at Nagpur. Six or seven years ago the time was probably not ripe for undertaking such experiments on a large scale. But the Fisherian technique has now become so familiar that it should not be difficult to start them in the immediate future.

Cultivation and rotation experiments

Other problems of special importance in India are connected with methods of cultivation and rotation of crops. Given soil and water, the basic problem is to secure the greatest return to the cultivator. A wide outlook is

desirable in designing such experiments. When we compare different methods of cultivation, for example, it is obviously not sufficient merely to concentrate attention on which method gives the largest yield of crop. It is also necessary to take into consideration the question of relative costs, the real aim being to find out which method will secure the largest net return to the cultivator. Similarly, in rotation experiments it is not enough to concentrate attention on merely the influence of a particular crop in one year on the yield of another crop in a succeeding year. The object should be to find out that particular sequence of crops which, after making allowances for differences in the cost of cultivation, would on an average secure the highest profit over a number of years.

Crop-cutting experiments

Although crop-cutting experiments do not fall under field trials, I would like to point out how such experiments may be made to supplement the information obtained from field experiments. Consider any given region. In an adequately designed crop-cutting experiment this region will be divided into a number of homogeneous zones with more or less the same type of soil, climate, irrigation facilities, type of crop, method of cultivation, etc. Suppose we now arrange to conduct the crop-cutting work at a number of spots selected strictly at random (but so arranged as to include all the varieties or conditions we desire to study) within each zone. The experiment as a whole will then resemble, on a very large scale, a field trial with a design of the randomized block type. I am not suggesting that in practice it will be possible to preserve the analogy in detail. But I think it should not be difficult to plan a crop-cutting experiment as a whole in such a way as to supply useful information regarding the performance of different varieties or treatments under actual cultivating conditions on a large scale.

Apart from such considerations, a crop-cutting experiment of course has its very important primary function of supplying information about the total out-turn of crop. As the only method available here is that of random samples, this question offers great scope for the application of statistical theory. Valuable pioneer work has been done in the United Provinces in this connexion, but the subject is of sufficient importance to deserve systematic and sustained study in other provinces.

Place of statistics in agriculture

Before concluding I would like to make a few general remarks about the place of statistics in agriculture. It is I hope sufficiently clear from the previous discussion that the first function of statistical theory is to supply an adequate technique for collecting the primary data in such a way that valid inferences may be drawn from them. The use of the principle of randomized replication in some form or other is indispensable for this purpose. The second function is to extract the whole of the information contained in the data in the most efficient way. It has been already pointed out that the appropriate method for this purpose will depend entirely on the particular way in which the process of randomization is introduced.

We have seen how successfully these principles have been used in the case of field trials. It is essential that the same principles should also be applied in

the case of experiments of all other kinds. There is great scope for work in this direction in India. For, I am afraid, the need of statistical methods in experiments other than field trials has not yet been sufficiently recognized in this country. Much effort and time have been wasted in consequence.

Need of definite statistical objects

In fact it would be a salutary practice in most experimental studies to refrain from taking any measurements or recording any observations whatsoever until one was satisfied that these could be utilized in a valid manner for some useful purpose. In any case, it would be a safe rule to carry out a trial analysis with available material at the earliest opportunity. If this was done, it would often reveal gaps in the data or defects in the method of collecting them which could be often put right in time. If one waited until the end it would usually be too late.

Indeed in India it is tragic to see the enormous amount of statistical material which is collected at considerable expense but which is never used, or which can never be used in any way except as food for white ants. It would save a great deal of labour and money if no measurements or observations were recorded without a definite statistical purpose in view.

As already pointed out, in order to secure this end, the process of randomization and the projected method of analysis must be such that it would be possible to make precise statements as to the significance or non-significane of the results. When, as is usually the case, some previous information is already available, it is further necessary that the experiment should be designed in such a way that the expected precision is adequate for the purpose in view.

Statistics as a tool and not the end

Even this is not sufficient, something more is necessary. Before starting an experiment each worker should satisfy himself that, if the experiment is successful, something will be gained which is worth the time, labour, and money spent on it. I frankly confess that I have sometimes wondered whether this condition had been really fulfilled in the case of some of the agricultural experiments which I have had occasion to examine. I know that this is treading on dangerous grounds, but I do not think it can be emphasized too much that statistics is merely a means and not an end in itself. Wishart and Sanders [1936] have wisely remarked : ' In these days it is difficult, but very important to keep a sense of proportion over the question of experimentation. The statistical side has been given so much prominence in recent years that there is a real danger of statistics being regarded as the main interest in experimentation'.

Safeguards against statistical excesses

Agriculturists must not therefore allow statistics to degenerate into a kind of mysterious cult. The fundamental principles are easy to understand, and there is no reason why the experimenter should not take an intelligent interest in the designing of experiments. The statistician, owing chiefly to constant practice, is more skilled in handling certain technical tools which can be safely left to him. But it is the experimenter who is in a better position to judge the value of the experiment as a whole in its wider aspects.

Fortunately statistics itself may be used as a check against its own excess. It is possible, and possible only by statistical methods, to determine with

scientific precision the marginal (or additional) cost in money and human labour for obtaining any given amount of additional information or increased accuracy. In this way a kind of scientific cost accounting of experiments can be made possible, so that the experimenter may be guided in his decision by rational considerations.

Cooperation between agriculturists and statisticians

In India there is always a danger of our not being able to see the wood because of the trees. The only corrective is to keep the basic problem prominently in view. The experimenter should constantly remind the statistician (and also himself perhaps occasionally) that improving the standard of living of the 350 millions of our countrymen by increasing the produce of the earth is the ultimate aim of all agricultural experiments ; and that how far progress is made in this direction is the final test by which all work will have to be judged. This is the only way in which the agriculturist will be able to breathe life nto the dry bones of statistics. I therefore plead for a close, friendly, active, and fruitful cooperation between the agriculturist and the statistician in this task.

Appendix I

Mean squares in analysis of variance : Chinsurah complex experiment on rice, 1933-36

	Degrees of freedom	1933	1934	1936
Block	2	144098	359084	75533
Date of planting	4	2389142**	499687**	5417487**
Error	8	30461	40555	23907
Variety	2	708517**	564263**	385807**
Error	4	12455	19494	16339
Planting × Varieties	8	29608**	37276**	26112**
Error	16	4259	8181	3018
Spacing	2	64848**	4061	10809**
Seedling	2	32691**	5733	2028
Spacing × Seedling	4	1396	3221	905
Planting × Seedling	8	2484	5570	1236
Planting × Spacing	8	5320*	1814	970
Variety × Seedling	4	1112	10710*	1065
Variety × Spacing	4	1306	4898	1331
Planting × Variety × Seedling	16	3991*	2889	1305
Planting × Variety × Spacing	16	2952*	5347	1751
Planting × Seedling × Spacing	16	1442	1585	848
Variety × Seedling × Spacing	8	1198	4634	1050
Planting × Variety × Seedling × Spacing	32	947	2289	1779
Error	240	1364	2847	1882

* Indicates significance at 5 per cent level. ** Indicates significance at one per cent level.

NOTE.—The results are given for the three seasons 1933, 1934, and 1936 as the experiment failed in 1935 owing to drought. The test of significance indicates that the effects of the three varieties of rice, of the five dates of planting, and of their mutual interaction of the first order were appreciable in all the three seasons under observation. Variation of spacing also showed significant differences in 1933 and 1936 but not in 1934. Other effects were either insignificant or significant only for one season. A detailed examination showed that the variety called *bhasumanik* gave the highest yields at Chinsurah during all the three seasons. The first week of August was found to be the best date of planting; in fact the yield showed a distinct tendency to be lower if the transplanting was finished earlier or delayed by a fortnight. A close spacing and an increased number of seedlings per hole were necessary to insure against late transplantings, particularly in years of adverse rainfall distribution. But under a favourable monsoon, small variations in spacing or seedling numbers produced practically no differences in yield. Finally the superiority of one variety over another was not identical for all the dates of planting but was found to be significantly associated with the time of transplanting.

APPENDIX II

Note on variance, standard error, covariance, etc.

Let $x_1, x_2 \ldots\ldots\ldots\ldots x_n$ be the yields of n plots. Then the average yield is defined as $x = \dfrac{x_1 + x_2 \ldots\ldots\ldots\ldots x_n}{n}$ .....(1).

The 'deviation' (or 'error') of the yield is simply the difference between any individual yield and the average, i.e. $(x_1 - x)$, $(x_2 - x)$, etc. The 'sum of squares of deviations' is given by $(x_1 - x)^2 + (x_2 - x)^2 + \ldots\ldots\ldots\ldots (x_n - x)^2 \ldots\ldots$ (2).

The 'variance' of the yield is defined as the sum of squares of deviation divided by $(n-1)$, or

$$v = \frac{(x_1 - x)^2 + (x_2 - x)^2 + \ldots\ldots\ldots\ldots (x_n - x)^2}{(n-1)} \quad \ldots\ldots\ldots\ldots (3).$$

Here $(n-1)$ represents the 'degrees of freedom' which can be usually identified with the number of independent comparisons possible in any given case. In the present example, we can clearly have $(n-1)$ independent comparisons between the yields of n different plots.

It will be noticed that 'variance' represents a kind of average of the squares of deviations. The 'standard deviation' or 'standard error' is defined as the square root of the variance (which is sometimes also called the 'root-mean-square-deviation' or 'root-mean-square-error').

The variance defined in equation (3) is the variance of individual plots, and the corresponding standard deviation or standard error obtained by extracting the square root is the 'standard error per plot'.

The 'variance of the mean' of the yields, i.e. of x is obtained by dividing the variance of individual plots by n, the total number of plots concerned, i.e. is given by

$$\frac{v}{n} = \frac{(x_1 - x)^2 + (x_2 - x)^2 + \ldots\ldots\ldots\ldots (x_n - x)^2}{n\,(n-1)} \quad \ldots\ldots\ldots\ldots (4).$$

The 'standard error of the mean' is the square root of the above expression.

When more than one character (or variate) is present, the covariance of any two characters (or any two variates) is similarly defined as the sum of the products of the corresponding deviations divided by the degrees of freedom.

Thus if $(x_1, y_1)\ (x_2, y_2) \ldots\ldots\ldots (x_n, y_n)$ are the n pairs of values of the two characters, and x and y their respective averages, then the covariance is given by

$$\frac{(x_1-x)(y_1-y) + (x_2-x)(y_2-y) + \ldots\ldots\ldots (x_n-x)(y_n-y)}{(n-1)} \quad \ldots\ldots (5).$$

Main effect and interaction.—If we have p treatments (or factors) then the main effect of each treatment (or factor) is the mean value of the relevant treatment (or factor) for all combinations of the other factors. The main effect is thus obtained by taking the average over all plots in which this particular factor occurs.

When two or more factors or treatments are used at the same time as in complex (factorial) experiments, the total effect due to the joint influence of two (or more) factors may or may not be equal to the sum of the effects due to each of the factors taken separately. Interaction between the factors is defined as the magnitude of the departure (if any) from the total effect calculated on the additive hypothesis. When the different factors act independently the joint effect will be necessarily additive, and the interaction will be consequently nil.

In an experiment involving p factors, we can consider the factors in pairs, and we shall have one first-order interaction corresponding to each pair or $\frac{p(p-1)}{2}$ first-order interactions altogether. We can also consider the factors by threes, and in this case, if the first-order interactions are affected by the presence of the third factor, then we shall get second-order interactions. In the same way we can also consider higher order interactions, but usually high order interactions are of little practical importance.

REFERENCES

Allen, R. E. and Wishart, J. (1930). *J. Agric. Sci.* **20** (3), 130, 399

Christidis, B. G. (1931). *J. Agric. Sci.* **21** (1), 14

Fisher, R. A. (1923). *J. Agric. Sci.* **13**, 311

————(1926). *J. Min. Agric.* **33**, 503

————(1933). *Rothamsted Experimental Station Report*, p. 5

————(1935). *The Design of Experiments.* Edinburgh : Oliver and Boyd.

Report of the Royal Commission on Agriculture, 1928

Vaidyanathan, M. (1934). *Report Imp. Coun. Agric. Res.*

Wishart, J. and Sanders, H. G. (1936). *Principles and Practice of Field Experimentation.*

Yates, F. (1933). *Emp. Expt. Agric.* **1**, (2) 129

———— (1935). *J. Roy. Stat. Soc., Supp. II* (2), 181

———— (1937). *Imp. Bur. Soil Sci. Tech. Comm., No.* **35**

A NOTE ON THE ANALYSIS OF 3^3 AND 3^4 DESIGNS (WITH THREE-FACTOR INTERACTIONS CONFOUNDED) IN FIELD EXPERIMENTS IN AGRICULTURE

BY

M. VAIDYANATHAN, M.A., L.T., F.S.S.

AND

S. SUBRAMONIA IYER, M.A., F.S.S.

Imperial Council of Agricultural Research

(Received for publication on 19 December 1939)

INTRODUCTION

ON the recommendation of the Joint Committee of Field Experiments in Agriculture of the Imperial Council of Agricultural Research, certain suggestions for replanning of manurial experiments for rice and sugarcane were made to the provinces and states, and most of these have been accepted for adoption from 1939-1940 season. Of the designs suggested by the Committee, what are now known as ' factorial designs ' are important. These are on the lines of the designs adopted at the Rothamsted Experimental Station in England, which the senior author of this paper had the opportunity of examining in detail at close quarters during 1937. As the idea of ' confounding ' the effects with block differences is comparatively new to the agricultural experimenter in India, it may be stated even in the beginning that the object of ' confounding ' with the blocks is to reduce the block-size which will otherwise become huge in a factorial design involving a number of levels of different factors. This is done without disturbing the interpretation of main effects and interactions on which we are interested. Thus with a 3^4 design, (i.e. with 3 levels of each of 4 factors), in the usual randomised block method there would be 81 plots in a block, which is obviously too huge for a correct interpretation ; but if it is possible to confound some of the higher order interactions (say three or four factor interactions) with the blocks, without disturbing the main effects and lower order interactions on which we are interested, the block size can be reduced with only those treatments included in a block giving the desired comparisons. Similarly in a 3^3 design, even 27 plots are too huge for a block and we may confound with the blocks some of the three-factor interactions.

Again, where we are dealing with a 3^4 design, if it is not possible to replicate and find sufficient space for the experiment, Fisher has shown that even with a single set of 81 plots (without replications) it will be a valid interpretation of the data if higher-order interactions are treated as error [See ' Design of Experiments ' p. 115 (second edition).]

But if it is possible to find space for a number of replications, then we may adopt what is known as ' partial confounding ', by which interactions confounded in one block are not confounded in the rest, and all ' confounded interactions ' are distributed over all the blocks, so that it may be possible to obtain some information for interactions confounded in one block from the blocks where they are not confounded.

The principles of planning and analysis of 3^3 and 3^4 designs have been dealt with by Yates in ' *The Design and Analysis of Factorial Experiments* ' (Technical Communication No. 35 of the Imperial Bureau of Soil Science). The object of this note is to explain fully the computations involved in the analysis of such designs so that they may be easily understood by the agricultural experimenter in India. Part I deals with 3^3 design and Part II with 3^4 design.

PART I

Analysis of 3^3 design (27 plots) split up into 3 sub-blocks of 9 plots each, such that 2 degrees of freedom of three-factor interactions are confounded with the three sub-blocks

We shall first illustrate the methods of analysis in the case of a 3^3 design (i.e. total of 27 plots) split up into 3 sub-blocks of 9 plots each such that 2 degrees of freedom of three-factor interactions are confounded with the three sub-blocks (note when 2 degrees of freedom are confounded with the blocks we want 3 sub-blocks, for 3 degrees of freedom 4 sub-blocks and so on).

Material

The data relate to an intercultural experiment on sugarcane conducted at Shahjahanpur, United Provinces, during 1938-39. The details of treatments are shown in Table I with the actual lay-out and plot yields.

The following are the details regarding the experiment :—

Size of plot 63 ft. × 24½ ft. = 1/28·24 or 0·0354 acre
Size of plot harvested 59 ft. × 17½ ft. = 1/42·19 or 0·0237 acre
Basal manuring—*Nil.*
Irrigation—*Vide* treatments in the experiment
Variety of cane—Co 312
System of planting.—Planted on flat 3½ ft. apart in rows on 27th January 1938
Experiment—Unreplicated into higher order interactions used as ' error '

The following statistical procedure is suggested in analysing the data :—

Formation of totals

Table I gives the plan of layout and plot yields ; d, s, n standing for interculture, irrigation and nitrogen respectively. d, s, n are written in the same order and rank throughout. From Table I we obtain Table II, arranged in a conventional way ; d_0, d_1, d_2 written down, s_0, s_1, s_2 across, and n_0, n_1, n_2 further up also across. This way of writing down the data of yield of treatments has the advantage that we can form from it two-way tables, i.e. with two factors only with facility. (1), (2) and (3) of Table III give two-way

totals of *ds*, *dn* and *sn* with their marginal totals. (4) and (5) of Table III gives for each of n_0, n_1, and n_2 diagonal totals I and J formed out of the nine values (d_0, d_1, d_2) (s_0, s_1, s_2) as explained below :—

If the nine values are written in the following order :—

	1	4	7
(A)	2	5	8
	3	6	9

then

$$(I)\quad \begin{matrix} I_1 = 1+5+9 \\ I_2 = 2+6+7 \\ I_3 = 3+4+8 \end{matrix} \qquad (J)\quad \begin{matrix} J_1 = 1+6+8 \\ J_2 = 2+4+9 \\ J_3 = 3+5+7 \end{matrix}$$

It may be noted that (A), (I) and (J) have the first columns identical, second and third columns of both (I) and (J) are permutations of second and third columns of (A), I_1 is top left-bottom right diagonal of (A), J_3 is top-right bottom left diagonal and that row-wise both (I) and (J) add up to 15.

These I and J totals will be found useful for calculating two-factor interactions. Similarly for calculating three-factor interactions, we form diagonal totals out of (n_0, n_1, n_2) (I_1, I_2, I_3), (n_0, n_1, n_2), (J_1, J_2, J_3) in the same way as original I and J were formed. We thus obtain W_1, W_2, W_3 ; X_1, X_2, X_3 ; Y_1, Y_2, Y_3 and Z_1, Z_2, Z_3 as given in Table IV. Now the totals X_1, X_2, X_3 are those of the three sub-blocks, showing that the particular 2 degrees of freedom are confounded with the blocks.

Analysis of variance

First calculate the total sum of squares of the 27 values in the usual way [i.e. square each of the 27 values, add all the squares, and subtract the correction factor :—

$$\frac{(\text{total of the 27 values})^2}{27}].$$

Then Table V gives sums of squares for the main effects and two-factor interactions calculated from the totals of the three two-way Tables of Table III*a* (See details of working).

The sum of squares corresponding to the confounded and unconfounded pairs of degrees of freedom of the three-factor interactions are found from Table IV, from (W), (X), (Y), (Z), remembering that W_1, W_2 ..... are totals of nine plots.

(*Check* :—The total sum of squares for 26 degrees of freedom on the basis of 26 values should tally with the sums of squares for 26 degrees of freedom got independently as explained above).

Table V further gives the analysis of variance into two-factor and three-factor interactions split up respectively into I, J ; W, X, Y, Z. Though it may not be necessary always to split up into above sets the process will help an understanding of the method of analysis, and explain the procedure of ' confounding '. Of the three-factor interactions, as 2 degrees of freedom are confounded with blocks, the other 6 degrees of freedom are taken to constitute ' error '. On this basis, in this particular case none of the effects is significant at $P = 0{\cdot}05$.

TABLE I

Lay out — Field (G 6)

$d_0s_0n_0$ 20·68	$d_2s_0n_1$ 20·20	$d_0s_1n_1$ 21·00	Sub-block I
$d_1s_1n_0$ 20·45	$d_0s_2n_2$ 20·82	$d_2s_1n_2$ 18·88	
$d_1s_2n_1$ 19·77	$d_2s_2n_0$ 23·20	$d_1s_0n_2$ 19·30	
$d_0s_0n_2$ 19·25	$d_2s_0n_0$ 13·75	$d_1s_0n_1$ 18·87	Sub-block II
$d_0s_2n_1$ 22·19	$d_1s_2n_0$ 21·67	$d_2s_2n_2$ 19·76	
$d_1s_1n_2$ 19·50	$d_2s_1n_1$ 19·78	$d_0s_1n_0$ 20·63	
$d_1s_1n_1$ 21·95	$d_1s_0n_0$ 18·45	$d_2s_0n_2$ 17·20	Sub-block III
$d_2s_2n_1$ 22·70	$d_2s_1n_0$ 21·53	$d_1s_2n_2$ 24·52	
$d_0s_2n_0$ 20·75	$d_0s_1n_2$ 20·75	$d_0s_0n_1$ 17·97	

Treatments

Interculture	Irrigation	Nitrogen
Akola Hoe (d_0)	2 irrigations (s_0)	0 lb. (n_0)
Pt Junier (d_1)	4 irrigations (s_1)	100 lb. (n_1)
Kashi (d_2)	6 irrigations (s_2)	200 lb. (n_2)

TABLE II

Yields of separate treatment combinations

	n_0			n_1			n_2		
	s_0	s_1	s_2	s_0	s_1	s_2	s_0	s_1	s_2
d_0	20·68	20·63	20·75	17·97	21·00	22·19	19·25	20·75	20·82
d_1	18·45	20·45	21·67	18·87	21·95	19·77	19·30	19·50	24·52
d_2	13·75	21·53	23·20	20·20	19·78	22·70	17·20	18·88	19·76

TABLE III

Two-way tables for calculating main effects and two factor interactions

(1)

	s_0	s_1	s_2	
d_0	57·90	62·38	63·76	184·04
d_1	56·62	61·90	65·96	184·48
d_2	51·15	60·19	65·66	177·00

(2) (3)

	n_0	n_1	n_2	
d_0	62·06	61·16	60·82	
d_1	60·57	60·59	63·32	
d_2	58·48	62·68	55·84	
s_0	52·88	57·04	55·75	165·67
s_1	62·61	62·73	59·13	184·47
s_2	65·62	64·66	65·10	195·38

(4) (5)

	n_0	n_1	n_2
I_1	64·33	62·62	58·51
I_2	60·73	60·84	59·00
I_3	56·05	60·97	62·47
J_1	63·88	57·52	62·65
J_2	62·28	62·57	59·81
J_3	54·95	64·34	57·52
	181·11	184·43	179·98

TABLE IV

Three-factor interactions

	1	2	3
(*W*)	187·64	180·21	177·67
(*X*)	184·30	185·82	175·40
(*Y*)	183·97	189·27	172·28
(*Z*)	188·03	177·32	180·17

TABLE V

Analysis of variance

		Degrees of freedom	Sum of squares	Mean square	v_1/v_2
Main effects	*D*	2	3·9150	1·9575	
	S	2	50·1908	25·0954	Even this high ratio shows 'Not significant'.
	N	2	1·1890	0·5945	
Two factor interactions	*DS* *I*	2	2·2489	1·6216	
	DS *J*	2	4·2375		
	DN *I*	2	1·9389	2·1715	
	DN *J*	2	6·7471		
	SN *I*	2	0·2969	1·1938	
	SN *J*	2	4·4783		
DSN Three factor interactions	*W* (Error)	2	5·9651		
	X (Confounded with blocks)	2	7·0406	4·9325 (*W*, *Y*, *Z*)	
	Y (Error)	2	16·7925		
	Z (Error)	2	6·8373		
		26	111·8779		

Conclusions

None of the effects are significant even at $P = 0·05$

DETAILS OF WORKING

Table III (from Table II)

(1) $d_0 s_0 = 20·68 + 17·97 + 19·25 = 57·90$
$d_0 s_1 = 20·63 + 21·00 + 20·75 = 62·38$
$d_0 s_2 = 20·75 + 22·19 + 20·82 = 63·76$
and so on

(2) $d_0 n_0 = 20·68 + 20·63 + 20·75 = 62·06$
$d_0 n_1 = 17·97 + 21·00 + 22·19 = 61·16$
$d_0 n_2 = 19·25 + 20·75 + 20·82 = 60·82$
and so on

(3) $s_0 n_0 = 20·68 + 18·45 + 13·75 = 52·88$
$s_0 n_1 = 17·97 + 18·87 + 20·20 = 57·04$
$s_0 n_2 = 19·25 + 10·30 + 17·20 = 55·75$
and so on

(From Table II)

(4) & (5)

$$I_1 n_0 = 20{\cdot}68 + 20{\cdot}45 + 23{\cdot}20 = 64{\cdot}33$$
$$I_2 n_0 = 18{\cdot}45 + 21{\cdot}53 + 20{\cdot}75 = 60{\cdot}73$$
$$I_3 n_0 = 13{\cdot}75 + 20{\cdot}63 + 21{\cdot}67 = 56{\cdot}05$$

$$I_1 n_1 = 17{\cdot}97 + 21{\cdot}95 + 22{\cdot}70 = 62{\cdot}62$$
$$I_2 n_1 = 18{\cdot}87 + 19{\cdot}78 + 22{\cdot}19 = 60{\cdot}84$$
$$I_3 n_1 = 20{\cdot}20 + 21{\cdot}00 + 19{\cdot}77 = 60{\cdot}97$$

$$I_1 n_2 = 19{\cdot}25 + 19{\cdot}50 + 19{\cdot}76 = 58{\cdot}51$$
$$I_2 n_2 = 19{\cdot}30 + 18{\cdot}88 + 20{\cdot}82 = 59{\cdot}00$$
$$I_3 n_2 = 17{\cdot}20 + 20{\cdot}75 + 24{\cdot}52 = 62{\cdot}47$$

$$J_1 n_0 = 20{\cdot}68 + 21{\cdot}53 + 21{\cdot}67 = 63{\cdot}88$$
$$J_2 n_0 = 18{\cdot}45 + 20{\cdot}63 + 23{\cdot}20 = 62{\cdot}28$$
$$J_3 n_0 = 13{\cdot}75 + 20{\cdot}45 + 20{\cdot}75 = 54{\cdot}95$$

$$J_1 n_1 = 17{\cdot}97 + 19{\cdot}78 + 19{\cdot}77 = 57{\cdot}52$$
$$J_2 n_1 = 18{\cdot}87 + 21{\cdot}00 + 22{\cdot}70 = 62{\cdot}57$$
$$J_3 n_1 = 20{\cdot}20 + 21{\cdot}95 + 22{\cdot}19 = 64{\cdot}34$$

$$J_1 n_2 = 19{\cdot}25 + 18{\cdot}88 + 24{\cdot}52 = 62{\cdot}65$$
$$J_2 n_2 = 19{\cdot}30 + 20{\cdot}75 + 19{\cdot}76 = 59{\cdot}81$$
$$J_3 n_2 = 17{\cdot}20 + 19{\cdot}50 + 20{\cdot}82 = 57{\cdot}52$$

TABLE IV

From (4) of Table III

$$W_1 = 64{\cdot}33 + 60{\cdot}84 + 62{\cdot}47 = 187{\cdot}64$$
$$W_2 = 60{\cdot}73 + 60{\cdot}97 + 58{\cdot}51 = 180{\cdot}21$$
$$W_3 = 56{\cdot}05 + 62{\cdot}62 + 59{\cdot}00 = 177{\cdot}67$$
$$X_1 = 64{\cdot}33 + 60{\cdot}97 + 59{\cdot}00 = 184{\cdot}30$$
$$X_2 = 60{\cdot}73 + 62{\cdot}62 + 62{\cdot}47 = 185{\cdot}82$$
$$X_3 = 56{\cdot}05 + 60{\cdot}84 + 58{\cdot}51 = 175{\cdot}40$$
$$Y_1 = 63{\cdot}88 + 62{\cdot}57 + 57{\cdot}52 = 183{\cdot}97$$
$$Y_2 = 62{\cdot}28 + 64{\cdot}34 + 62{\cdot}65 = 189{\cdot}27$$
$$Y_3 = 54{\cdot}95 + 57{\cdot}52 + 59{\cdot}81 = 172{\cdot}28$$
$$Z_1 = 63{\cdot}88 + 64{\cdot}34 + 59{\cdot}81 = 188{\cdot}03$$
$$Z_2 = 62{\cdot}28 + 57{\cdot}52 + 57{\cdot}52 = 177{\cdot}32$$
$$Z_3 = 54{\cdot}95 + 62{\cdot}57 + 62{\cdot}65 = 180{\cdot}17$$

TABLE V

For D (2 D. F.)—

$$= \frac{(184{\cdot}04)^2 + (184{\cdot}48)^2 + (177{\cdot}00)^2}{9} - \text{C.F.}$$

$$= 11025{\cdot}8435 - 11021{\cdot}9285$$
$$= 3{\cdot}9150$$

For S (2 D. F.)—

$$= \frac{(165{\cdot}67)^2 + (184{\cdot}47)^2 + (195{\cdot}38)^2}{9} - \text{C. F.}$$

$$= 11072{\cdot}1193 - 11021{\cdot}9285$$
$$= 50{\cdot}1908$$

For N (2 D. F.)—

$$= \frac{(181\cdot11)^2 + (184\cdot43)^2 + (179\cdot98)^2}{9} - \text{C.F.}$$

$$= 11023\cdot1175 - 11021\cdot9285$$
$$= 1\cdot1890$$

For DS $\begin{cases} I \\ J \end{cases}$, we get from (1) of Table III

$$I_1 = 57\cdot90 + 61\cdot90 + 65\cdot66 = 185\cdot46$$
$$I_2 = 56\cdot62 + 60\cdot19 + 63\cdot76 = 180\cdot57$$
$$I_3 = 51\cdot15 + 62\cdot38 + 65\cdot96 = 179\cdot49$$

Then DS (I) (2 D. F.)—

$$= \frac{(185\cdot46)^2 + (180\cdot57)^2 + (179\cdot49)^2}{9} - \text{C.F.}$$

$$= 11024\cdot1774 - 11021\cdot9285$$
$$= 2\cdot2489$$

Similarly,

$$J_1 = 57\cdot90 + 60\cdot19 + 65\cdot96 = 184\cdot05$$
$$J_2 = 56\cdot62 + 62\cdot38 + 65\cdot66 = 184\cdot66$$
$$J_3 = 51\cdot15 + 61\cdot90 + 63\cdot76 = 176\cdot81$$

DS (J) (2 D. F.)

$$= \frac{(184\cdot05)^2 + (184\cdot66)^2 + (176\cdot81)^2}{9} - \text{C.F.}$$

$$= 11026\cdot1660 - 11021\cdot9285$$
$$= 4\cdot2375$$

For DN $\begin{cases} I \\ J \end{cases}$, we get from (2) of Table III

$$I_1 = 62\cdot06 + 60\cdot59 + 55\cdot84 = 178\cdot49$$
$$I_2 = 60\cdot57 + 62\cdot68 + 60\cdot82 = 184\cdot07$$
$$I_3 = 58\cdot48 + 61\cdot16 + 63\cdot32 = 182\cdot96$$

DN (I) (2 D. F.)

$$= \frac{(178\cdot49)^2 + (184\cdot07)^2 + (182\cdot96)^2}{9} - \text{C.F.}$$

$$= 11023\cdot8674 - 11021\cdot9285$$
$$= 1\cdot9389$$

Similarly,

$$J_1 = 62\cdot06 + 62\cdot68 + 63\cdot32 = 188\cdot06$$
$$J_2 = 60\cdot57 + 61\cdot16 + 55\cdot84 = 177\cdot57$$
$$J_3 = 58\cdot48 + 60\cdot59 + 60\cdot82 = 170\cdot89$$

DN (J) (2 D. F.)

$$= \frac{(188\cdot06)^2 + (177\cdot57)^2 + (179\cdot89)^2}{9} - \text{C.F.}$$

$$= 11028\cdot6756 - 11021\cdot9285$$
$$= 6\cdot7471$$

For $SN \begin{cases} I \\ J \end{cases}$, we get from (3) of Table III.

$I_1 = 52{\cdot}88 + 62{\cdot}73 + 65{\cdot}10 = 180{\cdot}71$

$I_2 = 62{\cdot}61 + 64{\cdot}66 + 55{\cdot}75 = 183{\cdot}02$

$I_3 = 65{\cdot}62 + 57{\cdot}04 + 59{\cdot}13 = 181{\cdot}79$

SN (*I*) (2 D. F.)

$$= \frac{(180{\cdot}71)^2 + (183{\cdot}02)^2 + (181{\cdot}79)^2}{9} - \text{C.F.}$$

$= 11022{\cdot}2254 - 11021{\cdot}9285$
$= 0{\cdot}2969$

Similarly,

$J_1 = 52{\cdot}88 + 64{\cdot}66 + 59{\cdot}13 = 176{\cdot}67$

$J_2 = 62{\cdot}61 + 57{\cdot}04 + 65{\cdot}10 = 184{\cdot}75$

$J_3 = 65{\cdot}62 + 62{\cdot}73 + 55{\cdot}75 = 184{\cdot}10$

SN (*J*) (2 D. F.)

$$= \frac{(176{\cdot}67)^2 + (184{\cdot}75)^2 + (184{\cdot}10)^2}{9} - \text{C.F.}$$

$= 11026{\cdot}4068 - 11021{\cdot}9285$
$= 4{\cdot}4783$ (From Table IV)

D. S. N.

W (2 D. F.)

$$= \frac{(187{\cdot}64)^2 + (180{\cdot}21)^2 + (177{\cdot}67)^2}{9} - \text{C.F.}$$

$= 11027{\cdot}8936 - 11021{\cdot}9285$
$= 5{\cdot}9651$

X (2 D. F.) (Confounded with blocks)

$$= \frac{(184{\cdot}30)^2 + (185{\cdot}82)^2 + (175{\cdot}40)^2}{9} - \text{C.F.}$$

$= 11028{\cdot}9651 - 11021{\cdot}9285$
$= 7{\cdot}0406$

Y (2 D. F.)

$$= \frac{(183{\cdot}97)^2 + (189{\cdot}27)^2 + (172{\cdot}28)^2}{9} - \text{C.F.}$$

$= 11038{\cdot}7213 - 11021{\cdot}9285 = 16{\cdot}7928$

Z (2 D. F.)

$$= \frac{(188{\cdot}03)^2 + (177{\cdot}32)^2 + (180{\cdot}17)^2}{9} - \text{C.F.}$$

$= 11028{\cdot}7658 - 11021{\cdot}9285$
$= 6{\cdot}8373$

PART II

Analysis of 3^4 design (81 plots in one complete replication : Two such replications)

As no experimental data are still available in India to illustrate the analysis of a 'confounded 3^4 design,' a set of uniformity trial data on sugarcane has been taken to explain the procedure. (For the data please see *Ind. J. Agric. Sci.* 6 part 3, 1936).

In this case, we have taken two complete replications. The degrees of freedom confounded are :—

8 D. F.

ABC (*W*)
ABD (*Y*) } Confounded in the first replication.
ACD (*Z*)
BCD (*X*)

8 D. F.

ABC (*X*)
ABD (*Z*)
ACD (*W*) } Confounded in the second replication.
BCD (*Y*)

(*W*, *X*, *Y*, *Z*, have been explained in the first part).

It will be noted that there are nine sub-blocks of nine plots each in each complete replication thus confounding the 8 D. F.

Total 'sum of squares'

(1) Table I*a* gives the yields of each plot (162 plots). (For convenience of numerical work deviations from 300·0 have been used).

The sum of squares due to 161 degrees of freedom is calculated from the 162 plot yields in the usual way, (i.e. the actual sum of squares of all the plot yields minus T^2/n where T is the grand total and n the number of plots). Similarly the sum of squares due to the 18 blocks can be calculated.

Sum of squares due to 81 treatments

(2) Table II*a* gives the yields of the 81 treatment combinations ($3 \times 3 \times 3 \times 3$), tabulated in the standard order as in the case of a 3^3 design. Sum of squares due to 80 degrees of freedom may be calculated from this table, and in the present case as some interactions are confounded with the blocks, and hence it will be useful only for checking, not necessary for the final analysis of variance. The correction factor is the same as in (1) above, viz. (grand total)^2/162). Each figure in this table being the total of two plot yields (two being the number of replications), the sum of the squares of these 81 totals should be divided by two before applying the correction factor.

Main effects and two-factor interactions

(3) Table III*a* gives the six two-way tables possible for all the six pairs of the four factors. Each figure in these tables is the total of 18 plot yields, the marginal totals being the sum of 54 plot yields. The sum of squares due to main effects A, B, C and D are calculated from the appropriate marginal totals (the divisor being 54, with the usual correction factor).

Sum of squares due to six two-factor interactions *AB*, *BC*...., etc., are calculated by forming the diagonal totals *I*'s and *J*'s as shown in the table.

Three-factor interactions

(4) Table IV*a* gives the four three-factor tables for calculating the three-factor interactions *ABC*, *ABD*, *ACD* and *BCD*.

As in the case of two-way tables the grand totals of each of these tables is the same as the grand total of all the 162 plots ; each figure representing the total of six plots.

From each of the three-factor tables, the corresponding *W*, *X*, *Y* and *Z* (2 D. F. each) totals are calculated as explained in Part I, and the sum of squares ignoring confounding may be calculated from these in the usual way, and can be used for checking the calculations as to whether the separate sums of squares all add up to the 80 degrees of freedom for treatments as shown above.

Block totals

Table V*a* : This table is intended to obtain the three-factor interactions after the elimination of effects, confounded with the blocks. The nine block totals of each of the replications are numbered as shown in the plan and then written down in the standard order, viz. :—

1	4	7
2	5	8
3	6	9

The marginal totals and also *I* and *J* totals of the above arrangement are then calculated for each complete replication.

Table VI*a* shows the procedure adopted to correct the *W*, *X*, *Y* and *Z* totals of the three-factor interactions, in order to get *W'*, *X'*, *Y'*, *Z'* from which the unconfounded part of the sums of squares are calculated, e.g., for *ABC* ; *W* of *ABC* (2 D. F.) is confounded in block I. Hence subtract the *J* totals of block I (*a*) (Table V*a*) from *W* to get *W'*. The general rule is that the confounded parts are given by :—

BCD—Column totals (Table V*a*).
ACD—Row totals ,,
ABD—*I* totals ,,
ABC—*J* totals ,,

(See Table VI *a*).

The sum of squares due to the unconfounded portions of the three-factor interactions are to be calculated from these totals remembering that the number of plots is different according as to whether the particular *W*, *X*, *Y* or *Z* is the full value or after allowing for confounding.

These processes are exactly similar to the case of the 3^3 design, the operations being merely repeated for the four three-factor interactions given in Table IV-*a*.

Calculation of the sum of squares due to 16 degrees of freedom for the four-factor interactions

(8) Table VII-*a* : From Table II-*a* and *I*'s and *J*'s of (*a b*) corresponding to *C*'s and *D*'s taken in succession are entered in Table VII-*a*. From these *W*, *X*, *Y*, *Z* of (*abc*) corresponding to d_0, d_1, d_2 are then calculated. These may be designated as W_d, X_d, Y_d and Z_d for d_0, d_1 and d_2.

Table VIII-*a* gives a rearrangement of these values.

(9) Table IX-*a*.—The *I* and *J* totals of Table VIII-*a* for W_d, X_d, Y_d, and Z_d give the totals for calculating the sum of squares (8 pairs of 2 D. F.each) due to 16 degrees of freedom of the *ABCD* interaction.

Full analysis of variance table is given in Table X-*a*.

Summary

1. The data of a 3^3 design used for a (cultural experiment on sugarcane at Shahjahanpur, during 1938-39) where some of the three-factor interactions are confounded in a single replication are used to illustrate the analysis in such cases.

2. Similarly for illustrating the procedure for analysing a confounded 3^4 design, as no data are so far available in India a set of uniformity trial data has been taken. The necessary statistical calculations have been given, and particular attention has been devoted to the computation of confounded and partially confounded three-factor interactions and unconfounded four-factor interactions.

3. The principles and notation employed in splitting the highest order interaction in a 3^n design have been explained in a logical way, in the Appendix.

Acknowledgements

Our thanks are due to Dr. A. K. Mitra, Economic Botanist, Shahjahanpur for his kind permission to include his data in this paper.

References

Yates (1937). *Design and Analysis of Factorial Experiments*, Technical Communication No. 35 of the Imperial Bureau of Soil Science.

Appendix

Explanation of notations I, J, W, X, Y, Z, etc.

If *I* and *J* denote the symbolic operators for forming the three diagonal totals in the standard way, from a 3 × 3 table written in the standard form, it is useful to see how the repeated operation of these symbols enables us to split the degrees of freedom of the highest order interaction in the case of a 3^n design.

Let (*ab*) denote the 3 × 3 table of '*a*' and '*b*'.

	b_0	b_1	b_2
a_0	1	4	7
a_1	2	5	8
a_2	3	6	9

Then *AB* (*I*) or in the notation we shall adopt *I* (*ab*) will stand for the diagonal totals I_1, I_2, I_3 of (*ab*) :—

$$I_1 = 1 + 5 + 9$$
$$I_2 = 2 + 6 + 7$$
$$I_3 = 3 + 4 + 8$$

Similarly J (ab) stands for :—

$$J_1 = 1 + 6 + 8$$
$$J_2 = 2 + 4 + 9$$
$$J_3 = 3 + 5 + 7$$

(*i*) *3 × 3 design* : Four degrees of freedom of the two-factor interactions are given by :—

$$I\,(ab) = 2 \text{ D. F.}$$
$$J\,(ab) = 2 \text{ D. F.}$$

(*ii*) *3 × 3 × 3 design* : Eight degrees of freedom of the three-factor interactions are given by :—

$$I\,\{I\,(ab),\ c\} = W\,(abc)^* = 2 \text{ D. F.}$$
$$J\,\{I\,(ab),\ c\} = X\,(abc) = 2 \text{ D. F.}$$
$$I\,\{J\,(ab),\ c\} = Y\,(abc) = 2 \text{ D. F.}$$
$$J\,\{J\,(ab),\ c\} = Z\,(abc) = 2 \text{ D. F.}$$

(*iii*) *3 × 3 × 3 × 3 design* : Sixteen degrees of freedom of the four-factor interactions are given by :—

$$I\,\{W\,(abc),\ d\} = O\,(abcd) = 2 \text{ D. F.}$$
$$J\,\{W\,(abc),\ d\} = P\,(abcd) = 2 \text{ D. F.}$$
$$I\,\{X\,(abc),\ d\} = Q\,(abcd) = 2 \text{ D. F.}$$
$$J\,\{X\,(abc),\ d\} = R\,(abcd) = 2 \text{ D. F.}$$
$$I\,\{Y\,(abc),\ d\} = S\,(abcd) = 2 \text{ D. F.}$$
$$J\,\{Y\,(abc),\ d\} = T\,(abcd) = 2 \text{ D. F.}$$
$$I\,\{Z\,(abc),\ d\} = U\,(abcd) = 2 \text{ D. F.}$$
$$J\,\{Z\,(abc),\ d\} = V\,(abcd) = 2 \text{ D. F.}$$

* $ABC\,(W)$ in Yates' notation.

TABLE Ia

Data of plot yields (deviations from 300·0 lb.)

(First number indicates the treatment and the second the plot yield)

I replication									II replication								
1			2			3			1			2			3		
1	1	89	1	5	82	1	9	60	1	1	7	1	9	—36	1	5	21
2	5	2	2	9	69	2	1	116	2	9	20	2	5	—7	2	1	—7
3	9	—39	3	1	28	3	5	6	3	5	—60	3	1	5	3	9	—4
4	6	37	4	7	10	4	2	20	4	8	68	4	4	—12	4	3	44
5	7	15	5	2	41	5	6	48	5	4	22	5	3	—35	5	8	32
6	2	56	6	6	71	6	7	45	6	3	—20	6	8	—57	6	4	51
7	8	84	7	3	54	7	4	68	7	6	3	6	2	22	7	7	64
8	3	30	8	4	78	8	8	102	8	2	146	8	7	14	8	6	67
9	4	38	9	8	63	9	3	40	9	7	56	9	6	76	9	2	89
4			5			6			4			5			6		
1	8	12	1	3	46	1	4	46	1	6	44	1	2	35	1	7	39
2	3	47	2	4	35	2	8	39	2	2	22	2	7	57	2	6	54
3	4	23	3	8	103	3	9	25	3	7	72	3	6	73	3	2	34
4	1	52	4	5	14	4	1	75	4	1	120	4	9	92	4	5	75
5	5	103	5	9	34	5	1	51	5	9	106	5	5	28	5	1	12
6	9	46	6	1	64	6	5	77	6	5	33	6	1	26	6	9	67
7	6	94	7	7	4	7	2	63	7	8	26	7	4	39	7	3	53
8	7	20	8	2	87	8	6	103	8	4	43	8	3	21	8	8	—1
9	2	28	9	6	38	9	7	88	9	3	5	9	8	11	9	4	61
7			8			9			7			8			9		
1	6	36	1	7	68	1	2	2	1	8	100	1	4	25	1	3	55
2	7	27	2	2	35	2	9	65	2	4	32	2	3	—30	2	8	—31
3	2	33	3	6	23	3	7	44	3	3	31	3	8	—58	3	4	61
4	8	58	4	3	53	4	4	25	4	6	49	4	2	15	4	7	50
5	3	57	5	4	30	5	8	44	5	2	20	5	6	15	5	6	5
6	4	38	6	8	67	6	3	71	6	7	0	6	9	11	6	2	5
7	1	13	7	5	40	7	5	40	7	1	24	7	9	9	7	5	—17
8	5	62	8	9	6	8	1	38	8	9	31	8	5	—40	8	1	59
9	9	—10	9	1	112	9	5	58	9	5	6	9	1	12	9	9	67

	b_0	b_1	b_2		d_0	d_1	d_2
a_0	1	4	7	c_0	1*	4	7
a_1	2	5	8	c_1	2	5	8
a_2	3	6	9	c_2	3	6	9

First figure of treatment — Second figure o treatment

Thus treatment '25' means $a_1 b_0 c_1 d_2$

TABLE II-*a*

Yields of 81 treatment combinations

d_0

	c_0			c_1			c_2		
	b_0	b_1	b_2	b_0	b_1	b_2	b_0	b_1	b_2
a_0	96	172	37	37	35	85	101	97	107
a_1	109	63	97	57	61	233	17	22	51
a_2	33	90	124	87	61	108	56	51	45

d_1

	c_0			c_1			c_2		
	b_0	b_1	b_2	b_0	b_1	b_2	b_0	b_1	b_2
a_0	71	13	107	103	89	23	80	86	97
a_1	67	52	121	—5	131	22	119	48	170
a_2	84	89	99	—54	110	64	96	82	114

d_2

	c_0			c_1			c_2		
	b_0	b_1	b_2	b_0	b_1	b_2	b_0	b_1	b_2
a_0	107	60	68	112	126	110	24	167	57
a_1	84	30	34	58	76	101	89	140	37
a_2	116	45	144	45	10	74	—43	113	57

TABLE III-*a*

	b_0	b_1	b_2
a_0	731	845	691
a_1	595	623	866
a_2	420	651	829

c_0	767	614	831
c_1	440	699	820
c_2	539	806	735

	b_0	b_1	b_2
d_0	593	652	887
d_1	561	700	817
d_2	592	767	682

	d_0	d_1	d_2
a_0	767	669	831
a_1	710	725	649
a_2	655	684	561

c_0	821	703	688
c_1	764	483	712
c_2	547	892	641

	c_0	c_1	c_2
a_0	731	720	816
a_1	657	734	693
a_2	824	505	571

Main effects

A (2 D. F) $= 1247 \cdot 12$
B (2 D. F) $= 3827 \cdot 27$
C (2 D. F) $= 593 \cdot 05$
D (2 D. F) $= 77 \cdot 57$

Two-factor Interactions

AB

$I_1 = 731 + 623 + 829 = 2183$
$I_2 = 595 + 651 + 691 = 1937$
$I_3 = 420 + 845 + 866 = 2131$

$J_1 = 731 + 651 + 866 = 2248$
$J_2 = 595 + 845 + 829 = 2269$
$J_3 = 420 + 623 + 691 = 1734$

For AB (4 D.F)

(S.S = S.S. due to I's + S.S. due to J's)

$$= \frac{26267240}{54} - \text{2C. F.}$$

$$= 4022 \cdot 95$$

BC

$I_1 = 767 + 699 + 735 = 2201$
$I_2 = 440 + 806 + 831 = 2077$
$I_3 = 539 + 614 + 820 = 1973$

$J_1 = 767 + 806 + 820 = 2393$
$J_2 = 440 + 614 + 735 = 1789$
$J_3 = 539 + 699 + 831 = 2069$

For *BC* (4 D.F.) as before

$$= \frac{26258790}{54} - 2 \text{ C. F.}$$

$$= 3866 \cdot 47$$

BD

$I_1 = 593 + 700 + 682 = 1975$
$I_2 = 561 + 767 + 887 = 2215$
$I_3 = 592 + 652 + 817 = 2061$

$J_1 = 593 + 767 + 817 = 2177$
$J_2 = 561 + 652 + 682 = 1895$
$J_3 = 592 + 700 + 887 = 2179$

For *BD* (4 D.F.)

$$= \frac{26132966}{54} - 2 \text{ C. F.}$$

$$= 1536 \cdot 39$$

AD

$I_1 = 767 + 725 + 561 = 2053$
$I_2 = 710 + 684 + 831 = 2225$
$I_3 = 655 + 669 + 649 = 1973$

$J_1 = 767 + 684 + 649 = 2100$
$J_2 = 710 + 669 + 561 = 1940$
$J_3 = 655 + 725 + 831 = 2211$

for *AD* (4 D. F.) as before

$$= \frac{26120284}{54} - 2 \text{ C. F.}$$

$$= 1301 \cdot 54$$

CD

$I_1 = 821 + 483 + 641 = 1945$
$I_2 = 764 + 892 + 688 = 2344$
$I_3 = 547 + 703 + 712 = 1962$

$J_1 = 821 + 892 + 712 = 2425$
$J_2 = 764 + 703 + 641 = 2108$
$J_3 = 547 + 483 + 688 = 1718$

For *CD* (4 D.F.) as before

$$= \frac{26402618}{54} - 2 \text{ C. F.}$$

$$= 6529 \cdot 95$$

AC

$I_1 = 731 + 734 + 571 = 2036$
$I_2 = 657 + 505 + 816 = 1978$
$I_3 = 824 + 720 + 693 = 2237$

$J_1 = 731 + 505 + 693 = 1929$
$J_2 = 657 + 720 + 571 = 1948$
$J_3 = 824 + 734 + 816 = 2374$

For *AC* (4 D. F.) as before

$$= \frac{26213570}{54} - 2 \text{ C. F.}$$

$$= 3029 \cdot 06$$

TABLE IV-*a*

	c_0			c_1			c_2		
	b_0	b_1	b_2	b_0	b_1	b_2	b_0	b_1	b_2
a_0	274	245	212	252	250	218	205	350	261
a_1	260	145	252	110	268	356	225	210	258
a_2	233	224	367	78	181	246	109	246	216

	d_0			d_1			d_2		
	b_0	b_1	b_2	b_0	b_1	b_2	b_0	b_1	b_2
a_0	234	304	229	254	188	227	243	353	235
a_1	183	146	381	181	231	313	231	246	172
a_2	176	202	277	126	281	277	118	168	275

	d_0			d_1			d_2		
	c_0	c_1	c_2	c_0	c_1	c_2	c_0	c_1	c_2
a_0	305	157	305	191	215	263	235	348	248
a_1	269	351	90	240	148	337	148	235	266
a_2	247	256	152	272	120	292	305	129	127

	d_0			d_1			d_2		
	c_0	c_1	c_2	c_0	c_1	c_2	c_0	c_1	c_2
b_0	238	181	174	222	44	295	307	215	70
b_1	325	157	170	154	330	216	135	212	420
b_2	258	426	203	327	109	381	246	285	151

TABLE IV*a*—*contd.*

Three-factor interactions

ABC

	c_0	c_1	c_2
I_1	786	766	631
I_2	696	509	732
I_3	730	684	717
J_1	750	789	709
J_2	872	606	791
J_3	590	564	580
W	2012	2011	2228
X	2202	2179	1870
Y	1936	2145	2170
Z	2105	2241	1905

ABD

	d_0	d_1	d_2
I_1	657	762	764
I_2	614	689	634
I_3	861	627	643
J_1	817	848	583
J_2	764	646	859
J_3	551	584	599
W	1989	2005	2257
X	1918	2019	2314
Y	2062	1931	2258
Z	2260	2211	1780

BCD

	d_0	d_1	d_2
I_1	598	933	670
I_2	925	558	490
I_3	609	587	881
J_1	834	547	1012
J_2	709	579	501
J_3	589	952	528
W	2037	2182	2032
X	1675	2739	1837
Y	1941	2673	1637
Z	2287	1784	2180

ACD

	d_0	d_1	d_2
I_1	808	631	597
I_2	830	623	525
I_3	494	824	919
J_1	651	648	630
J_2	578	747	623
J_3	903	683	788
W	2350	2251	1650
X	2157	2380	1714
Y	2186	1891	2174
Z	1957	2014	2280

TABLE V-*a*

Block I

312	425	334	1071
496	425	434	1355
500	617	395	1512
1308	1467	1163	

I_1 = 312 + 425 + 395 = 1132
I_2 = 496 + 617 + 334 = 1447
I_3 = 500 + 425 + 434 = 1359

J_1 = 312 + 617 + 434 = 1363
J_2 = 496 + 425 + 395 = 1316
J_3 = 500 + 425 + 334 = 1259

Block II

242	471	293	1006
—30	382	—41	311
348	394	254	996
560	1247	506	

I_1 = 242 + 382 + 254 = 878
I_2 = —30 + 394 + 293 = 657
I_3 = 348 + 471 — 41 = 778

J_1 = 242 + 394 — 41 = 595
J_2 = —30 + 471 + 254 = 695
J_3 = 348 + 382 + 293 = 1023

TABLE VI-*a*

ABC				
W	2012	2011	2228	
(*W*)′	1363	1316	1259	*J*'s totals of Table V*a* Block—I
	649	695	969	
X	2202	2179	1870	
(*X*)′	595	695	1023	*J*'s totals of Table V*a* Block—II
	1607	1484	847	
(*Y*)	1936	2145	2170	
(*Z*)	2105	2241	1905	

(*W*) = 68266·18 — 66049 = 2217·18
(*X*) = 203782 — 191454·86 = 12327·10
(*Y*) = 241815·20 — 241203·71 = 611·49
(*Z*) = 242261·68 — 241203·71 = 1057·97

ABD

	(*Y*)	2062	1931	2258	
	Y'	1132	1447	1359	*I*'s totals of Table V *B*1—I
		930	484	899	
	(*Z*)	2260	2211	1780	
	Z'	878	657	778	*I*'s totals of Table V B1—II
		1382	1554	1002	
	(*W*)	1989	2005	2257	
	(*X*)	1918	2019	2314	
	(*Y*)	70642·85 — 66049 = 4593·85			
	(*Z*)	197364·59 — 191454·86 = 5909·73			
	(*W*)	242040·65 — 241203·71 = 836·94			
	(*X*)	242771·87 — 241203·71 = 1568·16			

BCD

	X	1675	2739	1837	
	X'	1308	1467	1163	Column's total of Table V,
		367	1272	674	Block I
	Y	1941	2673	1637	
	Y'	560	1247	506	Column's total of Table V,
		1381	1426	1131	Block II
	(*W*)	2037	2182	2032	
	(*Z*)	2287	1784	2180	
	(*X*)	81738·85 — 66049 = 15689·85			
	(*Y*)	193325·85 — 191454·86 = 1870·99			
	(*W*)	241472·54 — 241203·71 = 268·83			
	(*Z*)	243804·17 — 241203·71 = 2600·46			

ACD

	Z	1957	2014	2280	
	(*Z*)'	1071	1355	1512	Row's totals of Table V, Block I
		886	659	768	
	W	2350	2251	1650	
	(*W*)'	1006	311	996	,, ,, Block II.
		1344	1940	654	
	(*X*)	2157	2380	1714	
	(*Y*)	2186	1891	2174	
	(*Z*)	67003·74 — 66049 = 954·74			
	(*W*)	222135·26 — 191454·86 = 30680·40			
	(*X*)	245460·09 — 241203·71 = 4256·38			
	(*Y*)	242236·17 — 241203·71 = 1032·46			

TABLE VII-*a*

	d_0		
	c_0	c_1	c_2
I_1	283	206	168
I_2	236	203	175
I_3	302	355	204
J_1	283	331	203
J_2	405	200	159
J_3	133	233	185
(*W*)	690	759	683
(*X*)	813	646	673
(*Y*)	668	841	623
(*Z*)	675	921	536

	d_1		
	c_0	c_1	c_2
I_1	222	298	242
I_2	263	128	298
I_3	218	57	352
J_1	281	235	332
J_2	179	148	319
J_3	243	100	241
(W)	702	562	814
(X)	577	913	588
(Y)	670	611	797
(Z)	700	655	723

	d_2		
	c_0	c_1	c_2
I_1	281	262	221
I_2	197	178	259
I_3	210	272	161
J_1	186	223	174
J_2	288	258	313
J_3	214	231	154
(W)	620	690	731
(X)	812	620	609
(Y)	598	693	750
(Z)	730	665	646

TABLE VIII-*a*

Four-factor interactions

	d_0	d_1	d_2
W_1	690	702	620
W_2	759	562	690
W_3	683	814	731
X_1	813	577	812
X_2	646	913	620
X_3	673	588	609
Y_1	668	670	598
Y_2	841	611	693
Y_3	623	797	750
Z_1	675	700	730
Z_2	921	655	665
Z_3	536	723	646

TABLE IX-*a*

From W_d

$I_1 = 690 + 562 + 731 = 1983$
$I_2 = 759 + 814 + 620 = 2193$
$I_3 = 683 + 702 + 690 = 2075$

$J_1 = 690 + 814 + 690 = 2194$
$J_2 = 759 + 702 + 731 = 2192$
$J_3 = 683 + 562 + 620 = 1865$

$484146 \cdot 07 - 482407 \cdot 42 = 1738 \cdot 65$ (4 D. F.)

From X_d

$I_1 = 813 + 913 + 609 = 2335$
$I_2 = 646 + 588 + 812 = 2046$
$I_3 = 673 + 577 + 620 = 1870$

$J_1 = 813 + 588 + 620 = 2021$
$J_2 = 646 + 577 + 609 = 1832$
$J_3 = 673 + 913 + 812 = 2398$

$487524 \cdot 26 - 482407 \cdot 42 = 5118 \cdot 84$

From Y_d

$I_1 = 668 + 611 + 750 = 2029$
$I_2 = 841 + 797 + 598 = 2236$
$I_3 = 623 + 670 + 693 = 1986$

$J_1 = 668 + 797 + 693 = 2158$
$J_2 = 841 + 670 + 750 = 2261$
$J_3 = 623 + 611 + 598 = 1832$

$484926 \cdot 70 - 482407 \cdot 42 = 2519 \cdot 28$

From Z_d

$I_1 = 675 + 655 + 646 = 1976$
$I_2 = 921 + 723 + 730 = 2374$
$I_3 = 536 + 700 + 665 = 1901$

$J_1 = 675 + 723 + 665 = 2063$
$J_2 = 921 + 700 + 646 = 2267$
$J_3 = 536 + 655 + 730 = 1921$

$485921 \cdot 33 - 482407 \cdot 42 = 3513 \cdot 91$

Total for 16 D. F. $= 3513 \cdot 91 + 2519 \cdot 28 + 5118 \cdot 84 + 1738 \cdot 65$
$= 12890 \cdot 68$

TABLE X-*a*

Analysis of variance

Due to		Degrees of freedom	Sums of squares	Mean square
Total		161	213707·29	
Main effects	*A*	2	1247·12	
	B	2	3827·27	
	C	2	593·05	
	D	2	77·57	
Two-factor interactions	*AB*	4	4022·95	
	AC	4	3029·06	
	AD	4	1301·54	
	BC	4	3866·47	
	BD	4	1536·39	
	CD	4	6529·95	
Three-factor interactions	*ABC* (*W'*)	2	2217·18	Partially confounded.
	ABC (*X'*)	2	12327·11	
	ABC (*Y*)	2	611·49	Unconfounded.
	ABC (*Z*)	2	1057·97	
	ABD (*W*)	2	836·94	Unconfounded.
	ABD (*X*)	2	1568·16	
	ABD (*Y'*)	2	4593·85	Partially confounded.
	ABD (*Z'*)	2	5909·73	
	ACD (*W'*)	2	30680·40	Partially confounded.
	ACD (*Z'*)	2	954·74	
	ACD (*X*)	2	4256·38	Unconfounded.
	ACD (*Y*)	2	1032·46	
	BCD (*X'*)	2	15689·85	Partially confounded.
	BCD (*Y'*)	2	1870·99	
	BCD (*W*)	2	268·83	Unconfounded.
	BCD (*Z*)	2	1600·46	
Four-factor interactions	*ABC*(*W*) *D*	4	1738·65	
	ABC (*X*) *D*.	4	5118·84	
	ABC (*Y*) *D*.	4	2519·28	
	ABC (*Z*) *D*	4	3513·91	
	Blocks	17	52890·84	
	Remainder	64	36417·86	
	Total	161	213707·29	

W', *X'*, etc., have been computed from the block where they are not confounded (for method of calculation see Table VI).

NOTES

NOTICE No. 4 OF 1939

THE following plant quarantine regulations and import restrictions have been received in the Imperial Council of Agricultural Research. Those interested are advised to apply to the Secretary, Imperial Council of Agricultural Research, New Delhi, for loan.

I. LIST OF U. S. DEPARTMENT OF AGRICULTURE, BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE, SERVICE AND REGULATORY ANNOUNCEMENTS

1. *Quarantine and other official announcements*
   (*i*) *Japanese Beetle Quarantine* (*No. 48*).—Modification of regulations.
   (*ii*) *Pink Bollworm Quarantine* (*No. 52*).—Modifications of regulations:-
      (*a*) to add okra to the list of articles interstate movement of which is restricted from regulated areas.
      (*b*) to further extend the regulated areas.

2. *Summaries of plant quarantine import restrictions*
   (*i*) *British Colony of Bermuda.*—Revision of the digest.
   (*ii*) *Republic of Colombia.*—Authorised ports of entry.
   (*iii*) *Republic of Argentina.*—Plants and parts of plants of Rosaceae.
   (*iv*) *Colony and Protectorate of Kenya.*—Importation of soil prohibited—Fruits to be certified—Addition to restricted areas.
   (*v*) *Mexico.*—Extension Quarantine No. 12 amended—Alfalfa Weevil.
   (*vi*) *Cuba.*—Importation of cotton seed into Isle of Pines prohibited.

II. OTHER ANNOUNCEMENTS

Jamaica (*B. W. I.*).—Government Notice No. 116—Restriction of importation of seed potatoes.

Kenya.—Government Notice No. 468—Addition to the list of restricted seeds—Potatoes.

Malta.—Government Notice No. 461—Colorado Beetle—Import restrictions regarding plants etc.

THE 28th INDIAN SCIENCE CONGRESS, BENARES JANUARY, 1941

DISCUSSIONS IN THE AGRICULTURAL SECTION

THE Agricultural Sectional Committee proposes to hold Discussions on the following subjects during the next Session of the Indian Science Congress to be held at Benares early in January 1941. Scientific workers in India who desire to contribute papers to the above discussions are requested to communicate with the undersigned. The Rules of the Indian Science Congress Association require that authors of such contributions should be members of the Association of some category.

DISCUSSIONS

1. Drought resistance in plants.

2. The need for the exploration of wild forms for the improvement of crops.

3. Quality in crops.

10 February 1940
Indian Institute of Science,
Hebbal P. O., Bangalore.

C. N. ACHARYA,
Recorder,
Agricultural Section.

THE MAYNARD GANGA RAM PRIZE

APPLICATIONS are invited for the award of the Maynard Ganga Ram Prize of Rs. 2,000 for the two years ending 31st December 1940, for a discovery or an invention or a new practical method which will tend to increase agricultural production in the Punjab on a paying basis. Competition for the prize is restricted to non-officials only, irrespective of caste, creed or nationality. Government servants are not eligible on this occasion. Essays and theses are not accepted. The prize will be awarded for something practically achieved as a result of work done after the prize was founded in 1925. Competitors in their applications must give a clear account of the history of their invention or discovery and must produce clear evidence that it is the result of their own work. In the case of an improved crop details of parentage, evolution and history and a botanical description are necessary.

The Managing Committee reserves to itself the right of withholding or postponing the prize if no satisfactory achievement is reported to it.

Entries should reach the Director of Agriculture, Punjab, Lahore, not later than 31st December 1940.

WOODHOUSE MEMORIAL PRIZE

IN memory of Mr. E. J. Woodhouse, late Economic Botanist and Principal of Sabour Agricultural College, who was killed in action in France in 1917, a biennial prize in the form of a silver medal and books of a combined value of Rs. 100 will be awarded to the writer of the best essay on a subject to be selected from the list noted below. The length of the essay should not exceed 4,000 words.

The competition is open to graduates of Indian Universities and to Deploma holders and Licentiates of recognized Agricultural Colleges in India who are not more than 30 years of age on the date of submission of their essays.

Papers should be forwarded to the Director of Agriculture, Bihar, Patna, before the 30th June 1940.

Failing papers of sufficient merit, no award will be made. Essays must be typewritten on one side of paper only.

Subjects for essay

1. The importance of physiological studies in modern plant breeding.
2. Dominant species as an index of soil texture.
3. Modern methods of inducing mutations and polyploidy and their value for Indian agriculture.
4. Problems of wheat improvement in India.

REVIEWS

Biological Abstract

MEN engaged in research in medicine, public health, ecology, agriculture, forestry, botany or zoology, geography, and other fields, will welcome the announcement that *Biological Abstracts* is undertaking a more complete abstracting and segregation of the current research literature in bioclimatology and biometeorology. The section *Bioclimatology-Biometeorology* will appear within the section *Ecology* in *Biological Abstracts*, and will be under the editorship of Mr. Robert G. Stone of the Blue Hill Observatory, Harvard University.

The increasing interest in climatic and meteorological factors in their relation to biology, medicine, and agriculture is one of the significant trends of modern science. Ecologists have long appreciated the importance of temperature, humidity, radiation, barometric pressure, wind movement, and meteorological factors generally, as important factors in controlling the distribution and abundance of animals and plants. Foresters, horticulturists, and entomologists have likewise been concerned with the interrelationships of climatic and meteorological factors to the organisms with which they work. The developments of air conditioning and aviation have lately brought other important research groups into the field resulting in an increasing amount of research. This is often the work of individuals and groups not now in effective contact with biologists, and frequently appears in periodicals not commonly consulted by biologists.

In all civilized nations diverse research groups have sprung into being which, though they often devote much attention to the same fundamental natural forces, still work in practical isolation from each other, with a different background of training, and associations, belonging to different societies meeting at different times and places, publishing in different journals, reading different literature, investigating different types of things. These groups, however, are beginning to apply common ideas and common methods to the study of situations that are basically similar. For example, techniques and concepts derived from a study of the influence of weather factors on the spread of influenza or the common cold are likely to have a very high transfer value as applied to the study of the spread or survival of plant disease or economic insects. Conversely, it should be possible for research workers in the field of public health to make use of many findings of the entomologists, foresters, ecologists, plant pathologists, and other biological groups.

The abstracting journals of broad scope, like *Biological Abstracts*, are admirably suited to the sort of synthesis of fundamental knowledge that this situation demands. In augurating this service *Biological Abstracts* will be fulfilling one of the functions for which it was originally intended : that of providing an effective tool for research workers by coordinating the literature of border-line fields.

Under the sectional publication plan this material will be found, at present, not only in Section A, *Abstracts of general biology*, but also under Section B, *Abstracts of experimental animal biology*, Section D, *Abstracts of plant sciences*, and Section E, *Abstracts of animal sciences*.

THE INDIAN JOURNAL OF AGRICULTURAL SCIENCE

RATES FOR SHORT PRINTS

Contributors are entitled to receive 30 free reprints; but additional copies can be had, provided notice is given at the time of returning the proofs. The rates for the supply of the first 50 additional reprints or parts thereof are annas 8 per type page. For the number of copies exceeding 50, the rates are as under :—

No. of Copies—> / No. of Pages ↓	25 copies	50 copies	75 copies	100 copies	125 copies	150 copies	175 copies	200 copies	225 copies	250 copies
	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.
One page	0 12	1 1	1 8	1 13	2 12	3 1	3 7	3 12	4 2	4 7
Two pages	0 13	1 6	2 0	2 7	4 0	4 6	4 14	5 4	5 11	6 1
1 to 4 ,,	0 15	1 8	2 3	2 11	5 6	5 14	6 6	7 0	7 9	8 1
1 to 8 ,,	1 6	2 3	3 1	3 13	6 11	7 6	8 2	9 0	9 13	10 9
1 to 12 ,,	2 0	3 1	4 4	5 5	10 9	11 9	12 10	13 12	14 12	15 12
1 to 16 ,,	2 6	3 12	5 3	6 7	11 13	13 2	14 6	15 12	17 0	18 4
1 to 20 ,,	3 1	4 10	6 6	7 15	15 10	17 3	18 12	20 5	21 13	23 6
1 to 24 ,,	3 7	5 5	7 4	9 1	16 14	18 11	20 8	22 5	24 1	25 14
1 to 28 ,,	4 1	6 3	8 7	10 8	20 12	22 13	24 13	26 15	28 15	30 15
1 to 32 ,,	4 8	6 14	9 0	11 10	22 0	24 5	26 9	28 15	31 3	33 7
1 to 36 ,,	5 2	7 12	10 9	13 1	25 13	28 7	30 15	33 8	36 0	38 9
1 to 40 ,,	9	8 6	11 7	14 4	27 1	29 15	32 11	35 8	38 4	41 1
1 to 44 ,,	6 3	9 4	12 11	15 11	30 15	34 0	37 0	40 2	43 2	46 3
1 to 48 ,,	6 10	9 15	13 9	16 14	32 8	35 8	38 12	42 2	45 6	48 11
1 to 52 ,,	7 4	10 13	14 12	18 5	36 1	39 11	43 3	46 11	50 3	53 12
1 to 56 ,,	7 10	11 8	15 10	19 7	37 5	41 3	44 15	48 11	52 7	56 4

In the case of articles containing plates, the cost of the plates will be extra at the following rates—

Black-and-white plates : 6 annas 6 pies per plate for the first 25 copies and 4 annas 6 pies for every additional 25 copies or part thereof.

Colour plates : Re. 1-2-6 per plate for the first 25 copies and 10 annas 6 pies for every additional 25 copies or part thereof.

ORIGINAL ARTICLES

THE GENUS *FUSARIUM*

III. A CRITICAL STUDY OF THE FUNGUS CAUSING WILT OF GRAM (*CICER ARIETINUM* L.) AND OF THE RELATED SPECIES IN THE SUB-SECTION ORTHOCERA, WITH SPECIAL RELATION TO THE VARIABILITY OF KEY CHARACTERISTICS.

BY

G. WATTS PADWICK

Imperial Mycologist, Imperial Agricultural Research Institute, New Delhi

(Received for publication on 21 November 1939)

INTRODUCTION

IN the second contribution of this series, Prasad and Padwick [1939] described briefly the fungus causing gram wilt, and gave reasons for placing it in the sub-section Orthocera of the main section Elegans in the genus *Fusarium*. They pointed out that it was impossible to make any more definite statement without carefully comparing the fungus with all known species of the sub-section and without a thorough understanding of the range of variability of the isolates. The necessary study has now been made and the many facts established are held to throw considerable light not only on this particular fungus but also on the whole sub-section to which it belongs. The section Elegans is of great importance from plant pathological considerations. It has perhaps eight representatives so far known in India some, if not all of which cause havoc amongst cultivated crops. A thorough understanding of the range of variability of these fungi is necessary if we are to place identifications, and therefore breeding for disease resistance, on a sure footing. It is for this reason that the sub-section Orthocera has been subjected to such an elaborate study.

The sub-section Orthocera has, according to the classification of Wollenweber and Reinking [1935], five species, and with varieties and forms the total number of representatives is twelve. Eleven of these were secured for this work from the Centraalbureau voor Schimmelcultures, Baarn, Holland, the remaining representative being *Fusarium conglutinans* var. *citrinum* Wr. (=*Fusarium citrinum* Wr.) which was not obtainable at Baarn and which Wollenweber no longer has in his collection. These, together with the gram wilt fungi and a species isolated from a wilting linseed plant (*Linum usitatissimum* L.) from Karnal, Punjab, were the fungi studied. The complete list of fungi is therefore as follows :—

F. bostrycoides Wr. and Rkg. (Baarn)
F. conglutinans Wr. (Baarn)
F. conglutinans Wr. var. *betae* Stewart (Baarn)
F. conglutinans Wr. var. *callistephi* Beach (Baarn)
F. orthoceras App. and Wr. (Baarn)
F. orthoceras App. and Wr. var. *apii* (Nelson and Cochran) Wr. and Rkg. (=*F. apii* Nelson and Sherbakoff) (Baarn)

F. orthoceras App. and Wr. var. *apii f.* 1 Wr. and Rkg. (=*F. apii* var. *pallidum* Nelson and Sherbakoff) (Baarn)
F. orthoceras App. and Wr. var. *pisi* Linford (Baarn)
F. orthoceras App. and Wr. var. *longuis* (Sherb.) Wr. (Baarn)
F. angustum Sherb. (Baarn)
F. lini Bolley (Baarn)
F. lini Bolley ? (isolated from Karnal, Punjab)
Fusarium species causing gram wilt (here designated F57, but called 'Type 2' by Prasad and Padwick)
Fusarium species causing gram wilt (here designated F92, but called 'Type 7' by Prasad and Padwick)
Fusarium species causing gram wilt (here designated F93, but called 'Type 8' by Prasad and Padwick)

The key to the identity of *Orthocera* Fusaria given by Wollenweber and Reinking omits *F. lini*. The characters necessary for distinguishing these fungi are as follows :—

(1) Presence or absence of pionnotes.
(2) Type of conidiophores (with bostrychoid branching or simple to branched in whorls).
(3) Colour of stroma (pale, brownish white to flesh-coloured or red, violet, reddish brown or rust-red).
(4) Type of plectenchyma—erumpent or smooth.
(5) Sizes of conidia.
(6) Pathogenicity.

These characters have been studied with the exception of the type of conidiophores (no sign of bostrychoid branching was found) and pathogenicity, a character which had to be taken for granted. Four experiments were conducted :

(1) The effect of different plant extract media, commonly used in the identification of species of *Fusarium*, on the key characters.
(2) The effect of temperature on the key characters.
(3) A study of pigment production by *Fusarium orthoceras* var. *apii f.* 1.
(4) The influence of asparagine on the key characters.

THE EFFECT OF DIFFERENT PLANT EXTRACT MEDIA, COMMONLY USED IN THE IDENTIFICATION OF SPECIES OF *FUSARIUM*, ON THE KEY CHARACTERS

The media used in this experiment were the following :—

Two per cent Potato Dextrose Agar.
Five per cent Potato Dextrose Agar.
Potato cylinders.
Steamed rice.

The media were prepared in the precise manner indicated by Wollenweber, Sherbakoff, Reinking, Johann and Bailey [1925], except that rice had to be steamed more than three times as proposed by these workers, in order to ensure complete sterilization under Indian conditions.

Cultures of the fungi were prepared on oatmeal agar for use in inoculating the agar slants of different media. When sufficiently grown, transfers were made of small portions of agar and mycelium to the four media, duplicate tubes being prepared.

It was intended to keep the tubes at a constant temperature of 20°C, but since at the time the difference between day and night temperature in the laboratory was sometimes as much as 18°C and only an ice-box was available for the purpose, great accuracy was not possible. During the first few days the temperature of the tubes was regularly 20°C in the morning but rose to 24° or 25°C for a brief period in the evening. After the first week the temperature remained steady at 19½° to 20½°C for the next twenty days, by which time observations were completed excepting a few notes of minor importance on colours of colonies and substrata.

Colours of the aerial mycelium and the substrate (i.e. the agar surface) were noted on the ninth and twenty-first days after inoculation. They are recorded in Tables I to IV. On the forty-fourth day the colours of the rice substrate were again noted. No change had occurred since the twenty-first day. Sufficient quantity of two per cent KOH solution was then passed into the tubes to cover the agar slope. The following day the colours were again noted. They are recorded also in Table I. The colour nomenclature of Ridgway [1912] was used throughout this work. Notes on abundance of aerial mycelium, presence or absence of a 'stroma', and type of conidia in the aerial mycelium, taken on the 22nd to 24th days after inoculation, are recorded in Tables V to VIII. Measurements of fifty microconidia of each culture on potato dextrose agar were made on the nineteenth and twentieth days. These measurements are given in Table IX.

The following are the conclusions of main importance drawn from experiment 1 :—

(1) Apart from (*i*) pale Russian blue aerial mycelium produced by *F orthoceras* var. *pisi* on two per cent potato dextrose agar, and (*ii*) certain very pale and indefinite colours such as, ivory yellow, sea-shell pink, salmon buff, etc., all the cultures produced white aerial mycelium and a white or pale colour on the surface of the substrate or plectenchymatous stroma, or else produced a purple or closely related hue varying in tone and shade in both aerial mycelium and substrate, which always became plum purple or of a bluish violet hue on addition of KOH. The fungi thus fall in three groups :—

(*a*) The blue pigmented fungus. *F. orthoceras* var. *pisi*.

(*b*) The purplish pigmented group, including *F. bostrycoides*, *F. orthoceras*, *F. orthoceras* var. *apii*, *F. orthoceras* var. *longuis*, *F. angustum*, *F. lini*.

(*c*) The non-pigmented group, including *F. conglutinans*, *F. conglutinans* var. *betae*, *F. conglutinans* var. *callistephi*, *F. orthoceras* var. *apii f.*1, the gram wilt organisms.

Thus whereas all varieties of *F. conglutinans* were non-pigmented, the five forms of *F. orthoceras* fell within three groups.

(2) The pigments were produced best on rice. On five per cent potato dextrose agar only *F. angustum* and *F. lini* produced a definite pigment, on two per cent potato dextrose agar only *F. lini* produced it, and potato cylinders were quite unsuitable for pigment production.

(3) The colours present on the twenty-first day were generally speaking only an intensification of those on the ninth day.

(4) The fungi varied greatly in amount of aerial mycelium produced. Potato cylinders and five per cent potato dextrose agar were generally speaking very unfavourable for its production, though three cultures produced abundant mycelium on the former and two cultures which produced none on the former produced abundant aerial mycelium on the latter. Within the five varieties or forms of *F. orthoceras* and the three varieties of *F. conglutinans* there was no relationship at all as regards abundance of aerial mycelium.

(5) A true 'stroma' was absent throughout, but a plectenchymatous mat of hyphae reminiscent of a stroma sometimes occurred. This was not produced on rice mush or potato cylinders. On two per cent potato dextrose agar it was produced by the three varieties of *F. conglutinans* and the three gram wilt organisms, and on five per cent potato dextrose agar by the three varieties of *F. conglutinans*, the three gram wilt organisms, *F. orthoceras* var. *pisi* and *F. orthoceras* var. *longuis*.

(6) Steamed rice was not suitable for producing conidia in the aerial mycelium. *F. orthoceras* var. *pisi* produced conidia in the aerial mycelium only on two per cent potato dextrose agar, and then only a few spores. All the other cultures behaved more or less alike, and all the media except rice were suitable for production of spores in the aerial mycelium whenever the latter was formed.

(7) All the cultures were alike on all media in the following characteristics :—

(i) None produced chlamydospores by the twenty-second to twenty-fourth days after inoculation.

(ii) None produced sclerotia.

(iii) None produced sporodochia or pionnotes.

(iv) The only conidia produced were those in the aerial mycelium and they were continuous, ovoid to spindle-shaped or slightly curved, rounded equally at both ends, and borne singly (not in false heads or chains).

These facts have therefore not been recorded in the tables.

As regards measurements of spores, there was a highly significant difference between the longest spored isolate F 93 (the gram wilt fungus), and the shortest spored, F 85 (*F. orthoceras* var. *apii f.*1). The figures are as follows :—

Isolate	Mean length (μ)	S. E.	Difference	S. E. of difference
F 85 . . .	7·0	0·21	4·0μ	0·67μ
F 93 . . .	11·0	0·64		

If we take the means of the *authentic* cultures only, we have F 85 as the shortest spored isolate, and F 84 as the longest spored, the figures being as follows :—

Isolate	Mean length (μ)	S. E.	Difference	S. E. of difference
F 85 . . .	7·0	0·21	3·7μ	0·51μ
F 84 . . .	10·7	0·46		

This difference is again highly significant, and it will be noted that both F 84 and F 85 are forms of *F. orthoceras* var *apii*. It may be added that the gram wilt organism F 93 had significantly larger conidia than the other two gram wilt organisms, F 57 and F 92.

TABLE I

Colours of aerial mycelium and surface of substrate of rice cultures on the ninth and twenty-first days, and after adding potassium hydroxide on the forty-fourth day

Culture	Aerial mycelium		Surface of Substrate		
	9th day	21st day	9th day	21st day	44th day (with KOH)
F 79 *F. bostrycoides*	White . .	White .	Vinaceous drab and Payne's gray	Vinaceous drab .	Blue-violet black
F 80 *F. congluti-nans*	White . .	White . .	Seashell pink .	White and seashell pink	White
F 81 *F. congluti-nans* var. *betae*	White . .	White . .	Unchanged .	Unchanged .	Honey yellow
F 82 *F. congluti-nans* var. *calli-stephi*	White . .	White . .	Do. .	Ivory yellow .	Isabella colour
F 83 *F. orthoceras*	White . .	White and old rose	Orange vinaceous	Perilla purple .	Dull bluish violet
F 84 *F. orthoceras* var. *apii*	White . .	White and old rose	Light perilla purple and light pinkish lilac	Dark perilla purple and light perilla purple	Dark dull bluish violet
F 85 *F. orthoceras* var. *apii f.*1	White . .	White . .	Salmon buff .	Salmon buff .	White
F 73 *F. orthoceras* var. *pisi*	White . .	White . .	Unchanged .	Unchanged .	Deep mouse grey
F 86 *F. orthoceras* var. *longuis*	White . .	White, helle-bore red and argyle purple	Light perilla purple and light pinkish lilac	Dark perilla purple to light pinkish lilac	Plum purple
F 87 *F. angustum*	White . .	White, helle-bore red and argyle purple	Light perilla purple and rhodonite pink	Dark perilla purple to bishop's purple	Plum purple
F 74 *F. lini* .	White and purplish lilac	White and purplish lilac	Light perilla purple	Purplish lilac .	Plum purple
F 20 *F. lini* ? (Karnal)	White . .	White and orange vina-ceous	Perilla purple and light pinkish lilac	Dark perilla purple	Plum purple
F 57 Gram wilt organism	White . .	White . .	Unchanged .	Unchanged .	Seafoam green
F 92 Gram wilt organism	White . .	White . .	Unchanged .	Unchanged .	Cream buff
F 93 Gram wilt organism	White . .	White . .	Unchanged .	Unchanged .	White

TABLE II

Colour of aerial mycelium and surface of substrate of potato cylinder cultures on the ninth and twenty-first days

Culture	Aerial mycelium		Surface of substrate	
	9th day	21st day	9th day	21st day
F 79 *F. bostrycoides*	White	White	Pale olive buff	Ivory yellow
F 80 *F. conglutinans*	White	White	Ivory yellow	Ivory yellow
F 81 *F. conglutinans* var. *betae*	White	White	Ivory yellow	Ivory yellow
F 82 *F. conglutinans* var. *callistephi*	White	White	Ivory yellow	Ivory yellow
F 83 *F. orthoceras*	Lacking	Lacking	Ivory yellow	Ivory yellow
F 84 *F. orthoceras* var. *apii*	White and light pinkish lilac	Lacking	Ivory yellow	Ivory yellow
F 85 *F. orthoceras* var. *apii f.* 1	Lacking	Lacking	Ivory yellow	Ivory yellow
F 73 *F. orthoceras* var. *pisi*	White	White	White	Colourless
F 86 *F. orthoceras* var. *longuis*	White and light pinkish lilac	Lacking	Ivory yellow	Ivory yellow
F 87 *F. angustum*	White and ageratum violet	White and ageratum violet	Ivory yellow	Ivory yellow
F 74 *F. lini*	White with traces of purplish black	White	Ivory yellow	Ivory yellow and argyle purple
F 20 *F. lini* ? (Karnal)	White and purplish lilac	White and purplish lilac	Ivory yellow	Ivory yellow
F 57 Gram wilt organism	White	White	Unchnaged	Ivory yellow
F 92 Gram wilt organism	White	White	Unchanged	Unchanged
F 93 Gram wilt organism	White	White	Ivory yellow	Ivory yellow

TABLE III

Colour of aerial mycelium and surface of substrate of two per cent potato dextrose agar cultures on the ninth and twenty-first days

Culture	Aerial mycelum		Surface of substrate	
	9th day	21st day	9th day	21st day
F 79 *F. bostrycoides*	White	White	Pale olive buff	Ivory yellow
F 80 *F. conglutinans*	White	White and glaucus blue	White	White and pale glaucus blue
F 81 *F. conglutinans* var. *betae*	Pale olive buff	White	Pale olive buff	Pale olive buff
F 82 *F. conglutinans* var. *callistephi*	White	White	Ivory yellow	Ivory yellow
F 83 *F. orthoceras*	White	White	White	Ivory yellow
F 84 *F. orthoceras* var. *apii*	White	White and pale salmon colour	Ivory yellow	Ivory yellow
F 85 *F. orthoceras* var. *apii f.*1	White	White	White	White
F 73 *F. orthoceras* var. *pisi*	White and light gull grey	White and pale Russian blue	White	Deep bluish gray green
F 86 *F. orthoceras* var. *longuis*	White	White and shell pink.	White	White
F 87 *F. angustum*	White and light pinkish lilac	White and purplish lilac	White	White
F 74 *F. lini*	White and purplish lilac	White and purplish lilac	Purplish lilac	Ivory yellow and purplish lilac
F 20 *F. lini* ? (Karnal)	White and light perilla purple	White and light perilla purple	White	Ivory yellow
F 57 Gram wilt organism	White and salmon buff	White	Ivory yellow	Ivory yellow
F 92 Gram wilt organism	White	White	White	Unchanged
F 93 Gram wilt organism	White	White	White	Unchanged

TABLE IV

Colour of aerial mycelium and surface of substrate of five per cent potato dextrose agar cultures on the ninth and twenty-first days

Culture	Aerial mycelium		Surface of substrate	
	9th day	21st day	9th day	21st day
F 79 *F. bostrycoides*	White	White	Pale olive buff	White
F 80 *F. conglutinans*	White	White and pale glaucus blue	White	White and pale glaucus blue
F 81 *F. conglutinans* var. *betae*	Pale olive buff	White	Pale olive buff	Pale olive buff
F 82 *F. conglutinans* var. *callistephi*	White	White	Ivory yellow	Ivory yellow
F 83 *F. orthoceras*	White	White	White	Ivory yellow
F 84 *F. orthoceras* var. *apii*	White	White and pale salmon colour	Ivory yellow	Ivory yellow
F 85 *F. orthoceras* var. *apii f.*1	White	White	White	White
F 73 *F. orthoceras* var. *pisi*	White	White	White	White
F 86 *F. orthoceras* var. *longuis*	White	White	White	White
F 87 *F. angustum*	White and light pinkish lilac	White and purplish lilac	White	White
F 74 *F. lini*	White and purplish lilac	White and purplish lilac	Purplish lilac	Ivory yellow and purplish lilac
F 20 *F. lini* ? (Karnal)	White, light perilla purple and vinaceous pink	White, light perilla purple and vinaceous pink	White	Ivory yellow
F 57 Gram wilt organism	White	Lacking	Ivory yellow	Ivory yellow
F 92 Gram wilt organism	White	White	White	Unchanged
F 93 Gram wilt organism	White	White	White	White

TABLE V

Aerial mycelium, 'stroma' and conidia in aerial mycelium, on rice on the twenty-second to twenty-fourth days

Culture	Aerial mycelium	'Stroma'	Conidia in aerial mycelium
F 79 *F. bostrycoides*	Moderate	Absent	Vacuolated, very abundant
F 80 *F. conglutinans*	Moderate	Absent	Hyaline, few
F 81 *F. conglutinans* var. *betae*	Moderate	Absent	Absent
F 82 *F. conglutinans* var. *callistephi.*	Scanty	Absent	Vacuolated, very abundant
F 83 *F. orthoceras*	Scanty	Absent	Vacuolated, few
F 84 *F. orthoceras* var. *apii*	Moderate	Absent	Vacuolated, moderately abundant
F 85 *F. orthoceras* var. *apii f.*1	Scanty	Absent	Absent
F 73 *F. orthoceras* var. *pisi*	Moderate	Absent	Absent
F 86 *F. orthoceras* var. *longuis*	Moderate	Absent	Highly vacuolated, few
F 87 *F. angustum*	Moderate	Absent	Highly vacuolated, rare
F 74 *F. lini*	Moderate	Absent	Highly vacuolated, moderately abundant
F 20 *F. lini* ? (Karnal)	Moderate	Absent	Vacuolated, abundant
F 57 Gram wilt organism	Scanty	Absent	Sometimes constricted at middle, vacuolated, moderately abundant
F 92 Gram wilt organism	Moderate	Absent	Hyaline, few
F 93 Gram wilt organism	Scanty	Absent	Various distorted shapes, with swellings and sharp bends, hyaline, moderately abundant.

TABLE VI

Aerial mycelium, 'stroma', and conidia in aerial mycelium, on potato cylinders on the twenty-second to twenty-fourth days

Culture	Aerial mycelium	'Stroma'	Conidia in aerial mycelium
F 79 *F. bostrycoides*	Scanty	Absent	Vacuolated, very abundant
F 80 *F. conglutinans*	Moderate	Absent	Highly vacuolated, abundant
F 81 *F. conglutinans* var. *betae*	Abundant	Absent	Hyaline, moderately abundant
F 82 *F. conglutinans* var. *callistephi.*	Absent	Absent	Vacuolated, very abundant
F 83 *F. orthoceras*	Absent	Absent	Highly vacuolated, abundant
F 84 *F. orthoceras* var. *apii*	Absent	Absent	Highly vacuolated, very abundant
F 85 *F. orthoceras* var. *apii f.*1	Absent	Absent	Hyaline, moderately abundant
F 73 *F. orthoceras* var. *pisi*	Moderate	Absent	Absent
F 86 *F. orthoceras* var. *longuis*	Absent	Absent	Highly vacuolated, very abundant
F 87 *F. angustum*	Absent	Absent	Highly vacuolated, moderately abundant
F 74 *F. lini*	Abundant	Absent	Highly vacuolated, moderately abundant
F 20 *F. lini* ? (Karnal).	Absent	Absent	Sometimes constricted at middle, highly vacuolated, abundant
F 57 Gram wilt organism	Absent	Absent	Sometimes constricted at middle, vacuolated, very abundant
F 92 Gram wilt organism	Abundant	Absent	Hyaline, moderately abundant
F 93 Gram wilt organism	Absent	Absent	Highly vacuolated, moderately abundant

TABLE VII

Aerial mycelium ,' stroma ', and conidia in aerial mycelium, on two per cent potato dextrose agar on the twenty-second to twenty-fourth days

Culture	Aerial mycelium	' Stroma '	Conidia in aerial mycelium
F 79 *F. bostrycoides* .	Moderate .	Absent . .	Vacuolated, very abundant
F 80 *F. conglutinans* .	Scanty . .	Plectenchymatous	Hyaline, few
F 81 *F. conglutinans* var. *betae*	Scanty . .	Plectenchymatous	Vacuolated, few
F 82 *F. conglutinans* var. *callistephi*	Scanty . .	Plectenchymatous	Vacuolated, very abundant
F 83 *F. orthoceras* .	Moderate .	Absent . .	Hyaline, abundant
F 84 *F. orthoceras* var. *apii.*	Abundant .	Absent . .	Somewhat vacuolaetd, very abundant
F 85 *F. orthoceras* var. *apii f.* 1	Moderate .	Absent . .	Sometimes constricted at middle, vacuolated moderately abundant
F 73 *F. orthoceras* var. *pisi*	Moderate .	Absent . .	Hyaline, few
F 86 *F. orthoceras* var. *longuis*	Abundant .	Absent . .	Hyaline, very abundant
87 *F. angustum* .	Moderate .	Absent . .	Hyaline, moderately abundant
F 74 *F. lini* . .	Moderate .	Absent .. .	Highly vacuolated, few
F 20 *F. lini* ? (Karnal)	Moderate .	Absent . .	Hyaline, abundant
F 57 Gram wilt organism	Scanty . .	Plectenchymatous	Hyaline, very abundant
F 92 Gram wilt organism	Moderate .	Plectenchymatous	Hyaline, moderately abundant
F 93 Gram wilt organism	Short and thick	Plectenchymatous	Somewhat vacuolated, moderately abundant

TABLE VIII

Aerial mycelium ,' stroma,' and conidia in aerial mycelium, on five per cent potato dextrose agar on the twenty-second to twenty-fourth days

Culture	Aerial mycelium	'Stroma'	Conidia in aerial mycelium
F 79 *F. bostrycoides*	Scanty	Absent	Vacuolated, very abundant
F 80 *F. conglutinans*	Scanty	Plectenchymatous	Hyaline, few
F 81 *F. conglutinans* var. *betae*	Scanty	Plectenchymatous	Vacuolated, few
F 82 *F. conglutinans* var. *callistephi*	Absent	Plectenchymatous	Spores often constricted at middle and distorted, vacuolated, abundant
F 83 *F. orthoceras*	Scanty	Absent	Spores often constricted at middle and distorted, vacuolated, abundant
F 84 *F. orthoceras* var. *apii*	Abundant	Absent	Hyaline, very abundant
F 85 *F. orthoceras* var. *apii f.*1	Scanty	Absent	Vacuolated, few
F 73 *F. orthoceras* var. *pisi*	Scanty	Plectenchymatous	Absent
F 86 *F. orthoceras* var. longuis	Abundant	Plectenchymatous	Hyaline very abundant
F 87 *F. angustum*	Scanty	Absent	Hyaline, moderately abundant
F 74 *F. lini*	Moderate	Absent	Absent
F 20 *F. lini* ? (Karnal)	Moderate	Absent	Slightly vacuolated, abundant
F 57 Gram wilt organism	Scanty	Plectenchymatous	Hyaline, moderately abundant
F 92 Gram wilt organism	Scanty	Plectenchymatous	Hyaline, moderately abundant
F 93 Gram wilt organism	Scanty	Plectenchymatous	Hyaline, few

TABLE IX

Measurements of microconidia on two per cent potato dextrose agar on the nineteenth and twentieth days (means of fifty conidia)

Culture	Mean length (μ)	Mean breadth (μ)	Range (μ)
F 79 *F. bostrycoides* . .	8·6	3·5	5·1–14·3×1·7–5·1
F 80 *F. conglutinans* . .	9·9	3·4	6·8–18·0×2·0–4·4
F 81 *F. conglutinans* var. *betae*	Absent	..	....
F 82 *F. conglutinans* var. *callistephi*	10·3	2·4	7·8–19·4×1·7–4·1
F 83 *F. orthoceras* . .	9·0	3·2	5·4–15·0×2·4–4·4
F 84 *F. orthoceras* var. *apii* .	10·7	3·2	5·4–18·7×2·0–4·4
F 85 *F. orthoceras* var. *apii f.*1	7·0	3·0	4·4–10·2×1·7–4·1
F 73 *F. orthoceras* var. *pisi* .	Absent	..	....
F 86 *F. orthoceras* var. *longuis*	9·4	2·8	4·4–19·7×1·7–4·1
F 87 *F. angustum* . .	8·3	3·1	5·1–15·3×1·7–4·4
F 74 *F. lini* . . .	10·3	3·5	6·8–15·3×2·0–4·1
F 20 *lini* ? (Karnal) . .	9·1	2·9	6·1–15·3×1·7–4·1
F 57 Gram wilt organism .	8·2	3·5	4·1–15·3×1·7–5·1
F 92 Gram wilt organism .	8·2	3·2	3·4–16·3×2·0–6·8
F 93 Gram wilt organism .	11·0	3·4	5·1–26·5×2·0–7·8

EFFECT OF TEMPERATURE ON THE KEY CHARACTERS

The medium used in this experiment was oatmeal agar. It was prepared with only 30 grams of oatmeal to a litre of water, but in other respects it was prepared in a manner similar to that of Wollenweber, Sherbakoff, Reinking, Johann and Bailey. Twelve agar-slants were prepared from each isolate, six day old oatmeal cultures being used for the purpose. The cultures were divided into six lots, each containing two tubes of each isolate. The six lots were held at six different temperatures in dark incubators. After ten days notes were made of the colours of the surface of the substrate and the aerial mycelium, together with the amount of aerial mycelium. After a further ten days the colours were again noted. On the twentieth day note-taking began as regards other characters as well as colour production,

and it took six days to complete the work. These notes included the presence or absence of a stroma, the type of conidia on the surface of the medium, the presence or absence of a pionnotal layer, and the development of chlamydospores. It was not possible to take the more detailed observations at all temperatures, however, and consequently the temperatures 20° and 35°C were chosen for observations on conidia and chlamydospores except in one or two special cases where all temperatures were used.

The temperatures were recorded twice daily and the averages and ranges of the temperatures recorded during the period of the experiment were as follows :—

9·6°C (Range 8·5-11·0)

14·7°C (Range 14·0-16·0)

20·2°C (Range 17·5-23·0)

25·4°C (Range 25·0-26·5)

30·2°C (Range 27·5-32·0)

35·3°C (Range 34·5-36·5)

It will be noticed that the most difficult temperatures to maintain constant were those at 20, 25 and 30°C, which were nearest to room temperatures during the period. The means, however, were close to the required temperatures of 10, 15, 20, 25, 30 and 35°C, and throughout this paper the cultures growing in the various incubators are referred to as the 10° Series, 15° Series, etc. Since the purpose is to compare the reactions of the various cultures to all six different temperatures it has been necessary to arrange somewhat elaborate tables. The colour observations are recorded in Table X, and this table also has been utilized for the relative thickness of the plectenchymatous stromata. No sporodochia or sclerotia were found, but in the case of F 82 (*F. conglutinans* var. *callistephi*) there was a definite pionnotal layer on the surface of the agar at all temperatures, though it was very thin in the 10°C. In several other cases thin layers of spores were found on the agar surface, though they scarcely deserved the name pionnotes. These observations are also included in Table X.

Owing to the fact that the aerial mycelium had frequently collapsed by the twentieth day, observations on conidia were made on scrapings taken from the surface of the agar in many cases. If pionnotes or a thin layer of spores were present, these spores were also described. The descriptions of conidia and chlamydospores are given in Table XI. These descriptions are given only for the temperature series 20°C and 35°C. In many, though not all, cases, observations were made in some or all of the other temperature series, but since the descriptions given in Table XI clearly illustrate the general trend of the results and the other observations merely supplement the general conclusions, these observations have been omitted in order to simplify comparisons.

TABLE X

Colour of aerial mycelium and surface of substrate on the tenth and twentieth days, and thickness of plectenchymatous stroma and pionnotal layers on the twentieth to twenty-third days, at different temperatures

Culture	Temperature series, °C	Aerial mycelium		Surface of substrate		'Stroma'	Pionnotal layer
		10th day	20th day	10th day	20th day		
F 79 *F. bostrycoides*	10	— (0)	White (1)	Unchanged	Unchanged	Absent	Absent
	15	White (1)	White (2)	Do.	Do.	Do.	Do.
	20	White (1)	White (2)	Do.	Do.	Do.	Do.
	25	White (2)	White (2)	Do.	Do.	Do.	Do.
	30	White (2)	White (2)	Do.	Do.	Do.	Do.
	35	White (2)	White (2)	Do.	Do.	Do.	Do.
F 80 *F. conglutinans*	10	— (0)	White (1)	Unchanged	Unchanged	Absent	Absent
	15	White (1)	White (2)	Do.	Do.	Thin	Do.
	20	White (1)	White (2)	Do.	Do.	Do.	Do.
	25	White (3)	White (2)	Do.	Do.	Do.	Do.
	30	White (2)	White (3)	Do.	Do.	Do.	Do.
	35	White (2)	White (2)	Do.	Do.	Do.	Do.
F 81 *F. conglutinans* var. *betae.*	10	— (0)	White (1)	Unchanged	Unchanged	Absent	Absent
	15	— (0)	— (0)	Do.	Do.	Thin	Do.
	20	— (0)	White (1)	Do.	Do.	Do.	Do.
	25	White (1)	White (1)	Do.	Do.	Do.	Do.
	30	White (1)	White (1)	Do.	Do.	Do.	Do.
	35	White (1)	White (1)	Do.	Do.	Do.	Do.

TABLE X—*contd.*

Culture	Temperature series, °C	Aerial mycelium		Surface of substrate		'Stroma'	Pionnotal layer
		10th day	20th day	10th day	20th day		
F 82 *F. conglutinans* var. *callisteph.*	10	— (0)	White (1)	Unchanged	Unchanged	Absent	? A very thin layer.
	15	— (0)	White (1)	Do.	Do.	Thin	Pionnotes present
	20	— (0)	White (1)	Do.	Do.	Do.	Do.
	25	White (2)	White (1)	Do.	Cream buff	Do.	Do.
	30	White (1)	— (0)	Do.	Unchanged	Do.	Do.
	35	White (1)	— (0)	Do.	Do.	Do.	Do.
F 83 *F. orthoceras*	10	— (0)	Trace of purplish lilac (2)	Light perilla purple.	Light perilla purple.	Absent	Absent
	15	White (2)	Trace of purplish lilac (3)	Argyle purple	Light perilla purple.	Thin	Do.
	20	Trace of purplish lilac (3)	Trace of purplish lilac (3)	Bishop's purple	Perilla purple	Do.	Do.
	25	Trace of light purplish lilac (3).	Trace of Bishop's purple (3)	Light perilla purple.	Dark perilla purple	Do.	Do.
	30	Trace of purplish lilac (3)	Trace of purplish lilac (2)	Perilla purple	Perilla purple	Do.	Do.
	35	Trace of light lobelia violet (3).	Trace of purplish lilac (2)	Naphthalene violet.	Dark naphthalene violet.	Absent	Do.
F 84 *F. orthoceras* var. *apii.*	10	— (0)	Trace of purplish lilac (1)	Trace of light pinkish lilac.	Pale vinaceous lilac.	Absent	Absent
	15	White (1)	Trace of purplish lilac (2)	Purplish lilac	Light perilla purple.	Thin	? A very thin layer.
	20	Trace of purplish lilac (1)	Trace of purplish lilac (2)	Bishop's purple	Dark perilla purple.	Do.	Do.
	25	Trace of light purplish lilac (3)	Trace of bishop's purple (3)	Light perilla purple.	Do.	Do.	Do.
	30	Trace of purplish lilac (3)	Trace of purplish lilac (2)	Perilla purple	Perilla purple	Do.	Absent
	35	Trace of light lobelia violet (3)	Trace of purplish lilac (2)	Naphthalene violet.	Dark naphthalene violet.	Do.	Do.

F 85 *F. orthoceras* var. *apii, f.* 1.	10	— (0)	White (1)	Unchanged	Unchanged	Absent	Absent
	15	— (0)	White (2)	Do.	Do.	Thin	Do.
	20	Trace of purplish lilac (2).	Bishop's purple (2)	Do.	Dark plumbeous	Do.	Do.
	25	Trace of purplish lilac.*	Trace of purplish lilac (2).*	Do.	Plumbeous and dark perilla purple.*	Do.	Do.
	30	White (2)	White (1)	Do.	Unchanged	Do.	Do.
	35	White (3)	White (2)	Do.	Do.	Do.	Do.
F 73 *F. orthoceras* var. *pisi.*	10	— (0)	White (1)	Unchanged	Unchanged	Absent	Absent
	15	White (1)	White (2)	Do.	Trace of tilleul buff.	Thin	Do.
	20	White (1)	White (2)	Do.	Onion-skin pink	Do.	Do.
	25	White (3)	White (2)	Do.	Do.	Do.	Do.
	30	White (3)	White (3)	Vinaceous cinnamon	Light russet vinaceous.	Do.	Do.
	35	White (3)	White (2)	Wood brown	Dark vinaceous drab.	Do.	Do.
F 86 *F. orthoceras* var. *longuis.*	10	— (0)	Trace of purplish lilac (1)	Trace of light pinkish lilac.	Pale vinaceous lilac	Absent	? A very thin layer
	15	Trace of purplish lilac (1)	Trace of purplish lilac (2)	Purplish lilac	Light perilla purple.	Thin	Absent
	20	Trace of purplish lilac (2)	Trace of purplish lilac (2)	Bishops' purple	Light perill purple.	Do.	A very thin layer
	25	Trace of light purplish lilac (3)	Trace of bishop's purple (3)	Light perilla purple.	Dark perilla purple	Do.	Do.
	30	Trace of purplish lilac (3)	Trace of purplish lilac (2)	Perilla purple	Perilla purple	Do.	Do.
	35	Trace of light lobelia violet (3)	Trace of purplish lilac (2)	Nephthalene violet	Dark naphthalene violet.	Do.	Do.
F 87 *F. angustum*	10	— (0)	Trace of purplish lilac (2)	Purplish lilac	Light perilla purple.	Thin	Absent
	15	Trace of purplish lilac (2)	Trace of purplish lilac (3)	Argyle purple	Do.	Do.	Do.
	20	Trace of purplish lilac (3)	Trace of purplish lilac (3)	Light perilla purple.	Perilla purple	Do.	Do.
	25	Trac eof light purplish lilac (3)	Trace of purplish lilac (3)	Do.	Do.	Do.	Do.
	30	Trace of purplish lilac (3)	Trace of purplish lilac (2)	Perilla purple	Do.	Do.	? A very thin layer.
	35	Trace of light lobelia violet (3)	Trace of purplish lilac (2)	Naphthalene violet	Dark naphthalene violet.	Do.	Absent

TABLE X—*contd.*

Culture	Temperature series, °C	Aerial mycelium		Surface of substrate		'Stroma'	Pionnotal layer
		10th day	20th day	10th day	20th day		
F 74 *F. lini*	10	— (0)	White (1)	Unchanged	Light pinkish lilac	Absent	Absent
	15	— (0)	Traceof purplish lilac (2)	Purplish lilac	Light perilla purple.	Thin	Do.
	20	White (1)	Trace of purplish lilac (2)	Light perilla purple.	Dark perilla purple	Do.	? A very thin layer
	25	Trace of light purplish lilac (3)	Trace of purplish lilac (2)	Do.	Do.	Do.	Absent
	30	White (2)	Trace of purplish lilac (2)	Perilla purple	Perilla purple	Do.	? A very thin layer
	35	White (3)	Trace of purplish lilac (3)	Dark hyssop violet	Dark naphthalene violet.	Do.	Absent
F 20 *F. lini* ? (Karnal)	10	— (0)	Trace of purplish lilac (1)	Trace of pinkish lilac.	Light perilla purple.	Absent	Absent
	15	— (0)	Trace of dark hellebore red (2)	Vinaceous purple	Dark perilla purple	Thin	Do.
	20	Trace of purplish lilac (3)	Trace of purplish lilac (2)	Bishop's purple	Do.	Do.	Do.
	25	Trace of light purplish lilac (3)	White (3)	Light perilla purple.	Dull violet black	Do.	Do.
	30	Trace of purplish lilac (2)	Trace of purplish lilac (2)	Perilla purple	Dark perilla purple	Do.	? A very thin layer
	35	Trace of light hyssop violet (3)	Trace of light hyssop violet (3)	Dark hyssop violet	Dark hyssop violet	Do.	Absent
F 57 Gram wilt organism	10	— (0)	— (0)	Unchanged	Unchanged	Thin	Absent
	15	— (0)	White (1)	Do.	Do.	Do.	Do.
	20	White (1)	White (1)	Do.	Do.	Do.	Do.
	25	White (2)	White (1)	Do.	Do.	Do.	Do.
	30	White (1)	White (2)	Do.	Do.	Do.	Do.
	35	White (2)	White (1)	Do.	Do.	Do.	Do.

F 92 Gram wilt organism.	10	— (0) . . .	White (1) . .	Unchanged . .	Unchanged . .	Absent	Absent
	15	White (1) . . .	White (2) . .	Do. . .	Do. . .	Thin . .	Do.
	20	White (2) . . .	White (1) . .	Do. . .	Do. . .	Do. . .	Do.
	25	White (2) . . .	White (2) . .	Do. . .	Do. . .	Do. . .	Do.
	30	White (2) . .	White (2) . .	Do. .	Do. . .	Do. . .	Do.
	35	White (3) . . .	White (2) . .	Do. . .	Do. . .	Do. . .	Do.
F 93 Gram wilt organism.	10	— (0) . .	— (0) . .	Unchanged . .	Unchanged . .	Absent .	Absent
	15	White (1) . .	White (2) . .	Do. . .	Do. . .	Do. . .	Do.
	20	White (2) . . .	White (3) . .	Do. . .	Do. . .	Thin . .	Do.
	25	White (1) . . .	White (2) . .	Do. . .	Do. . .	Do. . .	Do.
	30	White (2) . . .	White (2) . .	Do. . .	Do. . .	Do. . .	Do.
	35	White (1) . . .	White (1) . .	Do. . .	Do. . .	Absent .	Do.

Footnote—

1. * Coloured at the top of one tube only.
2. The figures following the colours in columns 3 and 4 refer to the abundance of aerial mycelium: (0) Lacking; (1) Trace; (2) Moderate; (3) Abundant.

TABLE XI

Conidia and chlamydospores (Form of conidia and chlamydospores observed on the twenty-second and twenty-third days. Measurements made on the twenty-fourth and twenty-fifth days

Culture	Temperature series, °C	Conidia in aerial mycelium	Conidia in pionnotal layer	Chlamydospores
F 79 *F. bostrycoides*	20	Mainly single, but occasionally in false heads. Continuous, ovoid to spindle-shaped, hyaline. Abundant. 0-sept. 5·8μ long.	Pionnotes lacking . .	Absent
	35	Single. Continuous, ovoid to spindle-shaped, hyaline. Abundant 0-sept. 5·9μ long.	Ditto . . .	Terminal and intercallary. Single. 1 and 2-celled. Smooth. Hyaline. Abundant.
F 80 *F. conglutinans.*	20	Single. Continuous, ovoid to spindle-shaped, hyaline. Few. 0-sept. 8·8μ long.	Ditto . . .	Terminal and intercallary. Single and in chains. 1- and 2-celled. Smooth. Hyaline. Moderate numbers.
	35	Single. Continuous, ovoid to spindle-shaped, sometimes slightly curved, hyaline. Few 0-sept. 8·3 μ long.	Ditto . . .	Terminal and inter-callary. Single and in chains. 1- and 2-celled. Smooth or slightly rough. Hyaline. Abundant.
F 81 *F. congluti-nans* var. *betae.*	20	Single. Continuous and ovoid to spindle-shaped, hyaline, few. Rarely 1- or 3-septate and then spindle-shaped or slightly curved and bluntly tapering at both ends, with no foot-cell. Cell walls and septations indistinct, 0-sept. (96 per cent) 8·9μ, 1-sept. (4 per cent) 16·2μ long.	Ditto . . .	Intercallary. Single. 1- and 2-celled. Smooth. Hyaline Rare.

F 81 *F. conglutinans* var. *betae*.	35	Spores absent . . .	Pionnotes lacking . .	Terminal and intercallary. Single and in chains. 1-and 2-celled. Smooth. Hyaline. Moderate numbers.
F 82 *F. conglutinans* var. *callistephi*.	20	Aerial mycelium had collapsed, so that the spores could not be distinguished from those borne in pionnotes.	0-6-sept., the continuous spores ovoid to spindle-shaped, the septate spores spindle-shaped or slightly curved and bluntly tapering at both ends, with no distinct foot-cell. Cell walls and septations indistinct. Sometimes constricted at septations. Granular. Many spores containing chlamydospores. 0-sept. (79 per cent) 8·8μ, 1-sept. (12 per cent) 12·3μ, 3-sept. (5 per cent) 31·6μ, 4-sept. (2 per cent) 38·4μ, 5-sept. (1 per cent) 51·0μ, 6-sept. (1 per cent) 46·9μ, long.	Terminal and intercallary. Single. 1-celled. Smooth. Hyaline. Abundant.
	35	Aerial mycelium lacking .	0-5-sept., the continuous spores ovoid to spindle-shaped, the septate spores spindle-shaped or slightly curved and bluntly tapering at both ends, with no distinct foot-cell. Cell-walls and septations fairly distinct. Highly vacuolated. 0-sept. (68 per cent) 11·0μ, 1-sept. (26 per cent) 18·1μ, 2- sept. (4 per cent)33·1μ 3-sept. (2 per cent) 36·5μ long.	Difficult to observe method of bearing, owing to lack of mycelium, but apparently terminal and intercallary 1- and 2-celled. Smooth Hyaline. Abundant.

TABLE XI—*contd.*

Culture	Temperature series, °C	Conidia in aerial mycelium	Conidia in pionnotal layer	Chlamydospores
F 83 *F. orthoceras* .	20	Single. Continuous, rarely 1-sept.,. ovoid to spindle-shaped. Hyaline. Abundant. 0-sept. (96 per cent) 6·4μ, 1-sept. (4 per cent) 12·1μ long.	Pionnotes lacking . .	Terminal and intercallary. Single. 1- and 2-celled. Smooth. Hyaline Few.
F 83 *F. orthoceras* .	35	Single. Continuous, ovoid to spindle-shaped, rarely 1-or 2-sept., then sometimes slightly curved, bluntly tapering at both ends, septations indistinct. Highly vacuolated. Abundant. 0-sept., 7·5 long.	Pionnotes lacking . .	Terminal and intercallary. Single. 1- and 2-celled. Smooth. Hyaline. Abundant.
F 84 *F. orthoceras* var. *apii*.	20	Single. Continuous or 1-3-septate. Continuous spores ovoid to spindle-shaped. Septate spores spindle-shaped, sometimes slightly curved, bluntly tapering at both ends. Septations indistinct. Hyaline or slightly granular. Moderately abundant.	Usually continuous, occasionally 1-3-sept., ovoid to spindle-shaped, the longer spores slightly curved, rounded at both ends, with indistinct walls and septations, granular or vacuolated, often constricted at the septations. 0-sept. (88 per cent) 8·3μ, 1-sept. (12 per cent) 21·1μ long.	Terminal. Single. 1-celled. Smooth. Hyaline. Rare.
	35	Single. usually continuous, occasionally 1-2-sept., ovoid to spindle-shaped, septate spores sometimes slightly	Pionnotes lacking . .	Terminal and intercallary. Single. 1- and 2-celled. Smooth. Hyaline. Few.

		curved, bluntly tapering at both ends, septations indistinct. Highly vacuolated. Spores slightly constricted at septations. Moderately abundant. 0-sept. (96 per cent), 10·8μ, 1-sept. (4 per cent) 17·2μ long.		
F 85 *F. orthoceras* var. *apii* f. 1.	20	Single. Continuous. Ovoid to spindle-shaped. Hyaline. Rare. 0-sept. 7·2μ long.	Pionnotes lacking . .	Terminal and interncallary. Single. 1- and 2-celled. Smooth. Hyaline. Few.
	35	Spores absent . . .	Pionnotes lacking . .	Terminal and intercallary. Single. 1- and 2-celled. Smooth. Hyaline. Abundant.
F 73 *F. orthoceras* var. *pisi*.	20	Spores absent . . .	Pionnotes lacking . .	Terminal and intercallary. Single. 1-celled. Smooth. Hyaline. Moderate numbers.
	35	Single. Continuous. Ovoid to spindle-shaped. Hyaline, rare. 0-sept. (5 spores only) 5·6μ long.	Ditto . . .	Terminal and intercallary. Single. 1- and 2-celled. Some spores smooth, some very rough. Hyaline. Abundant.
F 86 *F. orthoceras* var. *longuis*.	20	Single. Continuous, ovoid to spindle-shaped, hyaline, abundant.	0-3-sept., ovoid to spindle-shaped, the longer spores sometimes slightly curved, rounded at both ends, thin-walled and very faintly septate. Granular. 0-sept. (88 per cent) 12·9μ, 1-sept. (10 per cent) 17·5μ, 2-sept. (2 per cent) 19·7μ long.	Absent.

TABLE XI—*contd.*

Culture	Temperature series, °C	Conidia in aerial mycelium	Conidia in pionnotal layer	Chlamydospores
	35	Single. Continuous or 1-sept., ovoid to spindle-shaped, sometimes slighty curved, with fairly distinct septations. Somewhat granular. Abundant.	Continuous or 1-sept., ovoid to spindle-shaped, sometimes slightly curved, rounded at both ends, thin-walled, hyaline. 0-sept. (90 per cent) 11·0μ, 1-sept. (10 per cent) 18·2μ long.	Terminal. Single. 1-celled. Smooth. Hyaline. Rare.
F 87 *F. angustum* .	20	Usually single, occasionally in false heads. Continuous, ovoid to spindle-shaped, hyaline, abundant. 0-sept. 7·1μ long.	Pionnotes lacking . .	Terminal and intercallary. Single. 1-celled. Smooth. Hyaline. Abundant.
	35	Single, continuous, ovoid to spindle-shaped, rarely 1-sept. with constrictions at the septa, septations indistinct. Granular. Abundant. 0-sept. 5·6μ long.	Ditto . . .	Terminal and intercallary. Single and in chains. 1-and 2-celled. Smooth. Hyaline. Abundant.
F 74 *F. lini* . .	20	Single, continuous or 1-sept., ovoid to spindle-shaped. Septations indistinct. Hyaline. Abundant.	Continuous to 3-sept., the continuous spores ovoid to spindle-shaped, the septate spores spindle-shaped and often slightly curved, tapering bluntly at both ends, cell walls and septations rather indistinct, hyaline. 0-sept. (79 per cent) 10·6μ,	Terminal and intercallary Single. 1- and 2-celled. Smooth. Hyaline. Few.

			1-sept. (14per cent) 19·0μ, 2-sept. (1 per cent) 28·9μ, 3-sept. (4 per cent) 46·3μ, 4-sept. (1 per cent) 62·9μ, 5-sept. (1 per cent) 68·0μ long.	
	35	Single, continuous and ovoid to spindle-shaped, rarely 0-3 sept. and gently tapering to blunt point at both ends, straight, septations indistinct. Hyaline. Abundant. 0-sept. 9·4μ long.	Pionnotes lacking . .	Terminal. Single. 1-celled. Smooth. Hyaline. Abundant.
F 20 *F. lini* ? (Karnal).	20	Single, continuous, rarely 1-sept., ovoid to spindle-shaped, hyaline, moderately abundant. 0-sept. (98 per cent) 7·0μ, 1-sept. (2per cent) 16·5μ long.	Ditto . . .	Intercallary. Single. 1-celled Hyaline. Smooth. Rare.
	35	Single, continuous and ovoid to spindle-shaped or 1- or 2-sept. and spindle-shaped or slightly curved and tapering to blunt point at both sends. Cell walls and septations fairly distinct. Hyaline. Abundant. 0-sept. (90 per cent) 9·4μ, 1-sept. (10 per cent) 18·7μ long.	Ditto . . .	Terminal and intercallary. Single. 1- and 2-celled. Smooth Hyaline. Abundant.
F 57 Gram wilt organism.	20	Single, continuous, ovoid to spindle-shaped, hyaline, Rare. 0-sept. 9·5μ long.	Ditto . . .	Absent

TABLE XI—*concld.*

Culture	Temperature series, °C	Conidia in aerial mycelium	Conidia in pionnotal layer.	Chlamydospores
	35	Single. Usually continuous, rarely 1-sept., ovoid to spindle-shaped, sometimes slightly curved, Hyaline. few. 0-sept. 9·1μ long.	Pionnotes lacking . .	Absent. (Six days later, on careful re-examination, two single, 1-celled, smooth, hyaline spores were found).
F 92 Gram wilt organism.	20	Single, continuous, ovoid to spindle-shaped. Few.	Ditto . . .	Intercallary. Single. 1-celled. Smooth. Hyaline. rare.
	35	Single, continuous or 1-sept., ovoid to spindle-shaped, sometimes slightly curved. Septations fairly distinct. Hyaline. Few. 0-sept. (96 per cent) 9·6μ, 1-sept. (4 per cent) 16·5μ long.	Ditto . . .	Terminal and intercallary. Single. 1- and 2-celled. Smooth. Hyaline. Moderately abundant.
F 93 Gram wilt roganism.	20	Single. Continuous, rarely 1-sept., ovoid to spindle-shaped, hyaline, few. 0-sept. (98 per cent) 10·6μ, 1-sept. (2 per cent) 20·4μ long.	Ditto . . .	Absent

35	Single. Usually continuous and ovoid to spindle-shaped, occasionally 1-3-sept. and spindle-shaped or slightly curved and tapering to blunt points at both ends. Cell walls and septations fairly distinct. Hyaline. Abundant. 0-sept. (98 per cent) 9·9μ, 1-sept. (2 per cent) 25·2μ long.	Ditto	. . .	Terminal and intercallary. Single. 1-celled. Smooth. Hyaline. Moderately abundant.	

The main conclusions from this experiment can be summarized as follows :—

(1) Except with *F. orthoceras* var. *apii f.* 1 the only effect of temperature on colour was a slightly more rapid production of pigment at the higher temperatures, at which the fungi grew more quickly, and a tendency towards production of a slightly more violet hue. All the cultures showing the purple pigment turned red with two per cent hydrochloric acid and violet or blue with two per cent potassium hydroxide.

F 85 (*F. orthoceras* var. *apii f.* 1) produced no pigment at 10°, 15°, 30° and 35°C. It produced purple aerial mycelium and dark plumbeous discoloration of the substrate at 20°C, and at 25°C one tube was not pigmented while the duplicate had a small patch of pigment at the thin end of the slant. (This particular tube formed the material for experiment 3).

(2) In general, the cultures showed the greatest amount of aerial mycelium at 20°, 25° and 30°C. Very little was produced at 10°C, and there was generally a falling off at 35°C. Casual observation suggested that this character was correlated with the rate of linear growth at the various temperatures, but no detailed records on this point were kept.

(3) All the cultures except *F. bostrycoides* had a thin plectenchymatous stroma, and in most cases this was present at all temperatures except 10°C.

(4) A thin pionnotal layer of spores was formed by *F. conglutinans* var. *callistephi*. Several cultures, namely *F. orthoceras* var. *apii*, *F. orthoceras* var. *longius*, *F. angustum* and *F. lini* had a very thin layer of spores almost too scanty to deserve the name 'pionnotal', though 'pionnotes' are referred to in Table XI. There was no regular relationship between temperature and the production of this very thin layer of spores.

(5) Abundance of spores in the aerial mycelium varied considerably with the different species, but a difference in temperature of 15°C (20° as compared with 35°C) had no appreciable effect. Spores were rare with *F. orthoceras* var. *apii f.* 1 and *F. orthoceras* var. *pisi*. The three other varieties of this species had abundant or moderately abundant spores in the aerial mycelium.

(6) Most of the cultures produced only continuous or 1-septate, ovoid, spindle-shaped or slightly curved spores in the aerial mycelium. The only ones producing 3-septate spores in the aerial mycelium were *F. conglutinans* var. *betae*, *F. orthoceras* var. *apii*, *F. lini*, and the gram wilt fungus F 93.

(7) The so-called pionnotes had more septate spores, and in the case of *F. conglutinans* var. *callistephi* occasional 4-5-6-septate spores were found. Even here, however, the non-septate spores totalled 68 per cent of the whole.

(8) The effect of temperature on either the number of septations or the length of spores of a given number of septations was slight. Averaging the lengths of all comparable sets of 0-septate spores in the aerial mycellium, namely *F. bostrycoides*, *F. conglutinans*, *F. orthoceras*, *F. angustum*, *F. lini*, and the two gram wilt fungi F 57 and F 93, the mean lengths at 20°C are 7·9μ and at 35°C, 8·0μ, a negligible difference. Insufficient 3-septate spores were available for comparison. *F. bostrycoides* had unusually small 0-septate spores, and *F. orthoceras* var. *longius* had rather large ones in the thin superficial or pionnotal layer. If the spores in the pionnotal layers of *F. orthoceras* var. *longuis* may strictly be compared with those in the aerial mycelium of *F. orthoceras*, the differences between these two varieties of one species is greater than the difference between any two species except *F. bostrycoides*.

(9) In most cases temperature had a marked effect on chlamydospore production, 35°C being favourable and 20°C unfavourable. The difference was most marked in the cultures of *F. bostrycoides*, *F. conglutinans* var. *apii f.* 1, *F. lini*, and the gram wilt fungi F 92 and F 93.

Production of pigment by *F. orthoceras* var. *apii f* 1

It is recorded in Table X that at the temperature 20°C culture F 85 (F. *orthoceras* var. *apii f.* 1 Wr. and Reink.=*F. apii* var. *pallidum* Nelson and Sherbakoff) produced a purplish lilac hue in the aerial mycelium and dark plumbeous in the substrate, and at 25°C also one tube showed a trace of colour at the shallow end of the agar. Since Nelson, Coons and Cochran [1937] say of this fungus ' Mycelium and substratum always colourless ' this colour production attracted particular attention.

From the tube showing a trace of colour, six transfers were made from the coloured portion and six from the white portion, on fresh oatmeal agar on the twenty-seventh day, and three fresh tubes were kept at 25°C. They were numbered, respectively, 1-6 W (from white portion) and 1-6 C (from coloured portion). When ten days old the colours were examined. The results are given in Table XII.

It is seen that the aerial mycelium of all cultures produced a mixture of white and purplish lilac, that the substrate was colourless at the bottom or deep end of all the slants, but that the top or shallow end of the substrate was coloured in one tube only in the case of the cultures from the colourless portion of the parent and in four tubes in the case of the cultures from the coloured portion of the parent tube. An attempt was then made to obtain by further sub-culturing, cultures which produced entirely colourless and others which produced entirely coloured colonies. In order to do this, transfers were again made, this time from the top and bottom portions of the slants of tubes 1W and 1C. Four cultures of each were made. This was done when the tubes were ten days old. These tubes were labelled as follows, and placed at 25° C:—

1 W T (inoculated from top of tube 1 W)

1 W B (inoculated from bottom of tube 1 W)

I C T (inoculated from top of tube 1 C)

1 C B (inoculated from bottom of tube 1 C).

TABLE XII

Colour production in F. orthoceras *var.* apii f. *1 Wr. and Reink.* (=F. api var. pallidum *Nelson and Sherbakoff*) *after ten days*

Tube No.	Nature of parent portion of culture	Colour of aerial mycelium		Colour of surface of substrate	
		Top of slant	Bottom of slant	Top of slant	Bottom of slant
1 W	Colourless . .	White and purplish lilac.	Light mouse gray	Unchanged .	Unchanged
2 W	Do. . .	Do. . .	Do. . .	Do. . .	Do.
3 W	Do. . .	Do. . .	Do. . .	Do. . .	Do.
4 W	Do. . .	Do. . .	Do. . .	Purplish lilac .	Do.
5 W	Do. . .	Do. . .	Do. . .	Unchanged .	Do.
6 W	Do. . .	Do. . .	Do. . .	Do. . .	Do.
1 C	Coloured . .	Do. . .	Do. . .	Purplish gray .	Do.
2 C	Do. . .	Do. . .	Do. . .	Unchanged .	Do.
3 C	Do. . .	Do. . .	Do. . .	Purplish gray .	Do.
4 C	Do. . .	Do. . .	Do. . .	Unchanged .	Do.
5 C	Do. . .	Do. . .	Do. . .	Purplish gray .	Do.
6 C	Do. . .	Do. . .	Do. . .	Do. . .	Do.

The same day transfers were also made from the original pair of cultures grown at 25°C which were by now 37 days old. These cultures also were prepared in quadruplicate, and they were marked thus :—

O W T (inoculated from top of original colourless tube)

O W B (inoculated from bottom of original colourless tube)

O C T (inoculated from top of original partially coloured tube)

O C B (inoculated from bottom of original partially coloured tube, but from the colourless portion)

In these eight series the replicate tubes were labelled a, b, c and d. Their colours were observed on the 11th and again on the 21st days. The colours observed on the twenty-first day are recorded in Table XIII.

At the conclusion of this experiment the tubes showing colours were divided into two groups, one of which had two per cent hydrochloric acid added, and the other 2 per cent potassium hydroxide. In all cases the purple or gray hues became red with hydrochloric acid and violet or blue with potassium hydroxide.

TABLE XIII

Colour production of F. orthoceras *var.* apii f. *1 Wr. and Reink.* (=F. apii *var.* pallidum *Nelson and Sherbakoff*) *in first and second sub-cultures from white and coloured tubes, after twenty-one days.*

First sub-culture

Culture*	Colour of aerial mycelium		Colour of surface of substrate	
	Top of tube	Bottom of tube	Top of tube	Bottom of tube
O W T a	White and argyle purple	White and light mouse gray	Unchanged . .	Unchanged
b	White and dark vinaceous gray	White and deep mouse gray	Do. . .	Do.
c	Do. . .	Do. . .	Do. . .	Do.
d	Do. . .	Do. . .	Do. . .	Do.
O W B a	White and vinaceous gray	White and argyle purple and light mouse gray	Do. . .	Ivory yellow
b	White . . .	White and mouse gray	Do. . .	Unchanged
c	White and purplish lilac	Do. . .	Do. . .	Ivory yellow
d	White and dark vinaceous gray	White and light mouse gray	Do. . .	Unchanged
O C T a	White . . .	Do. . .	Do. . .	Ivory yellow
b	White and dark vinaceous gray	Do. . .	Deep quaker drab .	Do.
c	White . . .	Do. . .	Unchanged . .	Do.
d	White and dark vinaceous gray	Do. . .	Do. . .	Unchanged
O C B a	Do. . .	Do. . .	Do. . .	Do.
b	Do. . .	Do. . .	Do. . .	Do.
c	Do. . .	Do. . .	Do. . .	Do.
d	Do. . .	Do. . .	Do. . .	Do.

*O W T—from top of original colourless tube.
O W B—from bottom of original colourless tube.
O C T—from top (coloured portion) of original coloured tube.
O C B—from bottom (colourless portion) of original coloured tube.

TABLE XIII—*contd.*

Second sub-culture

Culture†	Colour of aerial mycelium		Colour of surface of substrate	
	Top of tube	Bottom of tube	Top of tube	Bottom of tube
1 W T a	White and purplish lilac	White and light mouse gray	Pale vinaceous lilac.	Ivory yellow
b	Do.	Do.	Do.	Do.
c	Do.	Do.	Do.	Do.
d	Do.	White	Deep purplish vinaceous	Do.
1 W B a	Do.	White and light mouse gray	Unchanged	Do.
b	Do.	Do.	Vinaceous lavendar	Do.
c	White	Do.	Unchanged	Do.
d	White and purplish lilac	Do.	Do.	Do.
1 C T a	White	Do.	Do.	Do.
b	White and purplish lilac	White and deep mouse gray	Light vinaceous lilac	Do.
c	White	White and light mouse gray	Unchanged	Do.
d	White and purplish lilac	White and deep mouse gray	Light vinaceous lilac	Do.
1 C B a	White	White and light mouse gray	Unchanged	Do.
b	White and purplish lilac	Do.	Do.	Do.
c	Do.	Do.	Light vinaceous lilac	Do.
d	Do.	Do.	Unchanged	Do.

†1 W T—inoculated from top of colourless tube originating from colourless tube.

1 W B—inoculated from bottom of colourless tube originating from colourless tube.

1 C T—inoculated from top of coloured tube originating from coloured tube.

1 C B—inoculated from bottom of coloured tube originating from coloured tube.

The results of this experiment appear to indicate that both the origina coloured tube and the originally colourless one consisted of a mixture of two strains, one capable of producing a pigment with acid and alkali reactions typically those of the sub-section Orthocera, the other unable to do so. There was no indication that sub-culturing from the upper portions of the slant, where the colour was intense, would yield an intensely pigmented culture. If the coloured strain occurred as a saltant it must have done so at a stage previous to the inoculation of Experiment 1.

It is interesting to record that one of the most intensely coloured cultures was retained in the stock culture collection and has been sub-cultured four or five times. Its power to produce the pigment has dwindled but not entirely disappeared.

Influence of asparagine on the key characters

The purpose of this experiment was to find whether a variation in the asparagine content of a synthetic medium influenced the septation of spores, colour of mycelium and substrate, and other characters as found by Brown [1925] in *Fusarium fructigenum*.

The following fives cultures were used :—

F 74. *F. lini* Bolley :

In previous experiments this culture showed a distinct tendency to produce a purplish lilac colour in the aerial mycelium and a deep purple, lilac or violet hue in the substrate, varying presumably with the acidity or alkalinity of the medium. It also produced a thin layer of spores on the agar surface, resembling pionnotes. In nature, according to Wollenweber and Reinking [1935] it sometimes produces sporodochia, and in the form of the conidia is a bridge between *F. orthoceras* and *F. oxysporum*. It produced abundant chlamydospores at 35°C, few at 20°C.

F 85. *F. orthoceras* var. *apii f.* 1 Wr. and Reink. (=*F. apii* var. *pallidum* Nelson and Sherbakoff) :

This culture behaved peculiarly in regard to colour production, sometimes producing a purplish lilac colour in the aerial mycelium and perilla purple or dark plumbeous in the substrate, at other times having white aerial mycelium and producing no colour in the stroma. It produced no pionnotes and even non-septate small conidia in the aerial mycellium were few. It produced abundant chlamydospores at 35°C, few at 20° C.

F 57. Gram wilt fungus :

This culture produced no colour, and very rarely produced septate spores. Small conidia were few in the aerial mycelium. Production of chlamydospores was very rare at 35°C, and none were found at 20°C.

F 92. Gram wilt fungus :

Resembled F. 57 except in the moderate production of chlamydospores at 35°C and occasionally at 20°C.

F 93. Gram wilt fungus :

This culture, like F 57 and F 92, was colourless, but it produced some long 3-septate spores and the smaller spores in the aerial mycelium were more abundant than in either F 57 or F 92. Chlamydospores were moderately abundant at 35°C, though absent at 20° C.

The media used in the experiment were as follows :—

1. Glucose 2 gm.
   K_2PO_4 1·25 gm.
   $MgSO_4.7H_2O$ 0·75 gm.
   Agar 15 gm.
   Water 1 litre
2. Medium 1 plus 0·05 gm. asparagine

3. Medium 1 plus 0·10 gm. asparagine
4. Medium 1 plus 0·20 gm. asparagine
5. Medium 1 plus 0·50 gm. asparagine
6. Medium 1 plus 1·00 gm. asparagine
7. Medium 1 plus 2·00 gm. asparagine
8. Medium 1 plus 4·00 gm. asparagine
9. Oatmeal agar, using 100 gm. oatmeal per litre, steamed at 60°C for one hour, strained through muslin, sterilized at 10 lb. pressure for 45 minutes (20 gm. agar)
10. Plain agar (20 gm. per litre).

Four tubes of each medium were inoculated with each fungus from plain agar cultures, except in the case of F 93, tubes of which were inoculated from 3 per cent oatmeal agar because the growth on plain agar was unsatisfactory. The cultures were grown at 25°C. The replicates were labelled *a*, *b*, *c* and *d*, and these designations are used in Tables XV and XVI which summarize the observations on spore forms. The colours noted on the nineteenth day are recorded in Table XIV.

A most surprising feature of this experiment was the complete failure of the fungi to produce any pigment whatsoever on any of the synthetic media, in spite of excellent growth with an abundant covering of aerial mycelium. These media are known to be less satisfactory for colour production than similar media to which potato starch is added, but complete failure to produce colour by such a deeply pigmented culture as *F. lini* was not expected. Starch was deliberately omitted because Brown [1925] did not find it suitable for studying sporulation in the feebly sporing strains of *F. fructigenum* (=*F. ateritium*).

As was the case in experiment 2 on oatmeal agar, *F. orthoceras* var. *apii f.* 1 formed practically no septate spores. Its behaviour on other media was irregular. For instance, few spores were found on medium 5 containing 0·5 gm. of asparagine, but spores were present in abundance on media 4 and 6, containing 0·2 and 1·0 gm. of asparagine respectively. Spores were absent in medium 8, containing 4·0 gm. of asparagine. *F. lini* produced non-septate spores in media 1 (with rare exception), 2, 4 and 6. It produced 0-3-septate spores in two tubes of medium 3, one tube of medium 5, two tubes of medium 7 and one tube of medium 8. It produced only continuous spores on oatmeal agar and plain agar. Only medium 5 gave sufficient 3-septate spores of *F. lini* for a reliable average, and they measured $33 \cdot 2\mu \times 4 \cdot 1\mu$.

The lack of agreement between replicate tubes as regards chlamydospore production was most striking.

Discussion

It is not often possible in any genus of fungi containing a large number of species to name any single variable character the exact measurement of which will determine the species. It is in fact fairly widely accepted that a one-character difference, unless it is very great indeed, can hardly be considered to warrant anything higher than varietal rank. Moreover, when the particular character concerned is highly variable and responds readily to environmental changes, its value is considerably reduced.

TABLE XIV

Colour production on synthetic media and on plain agar and oatmeal agar after 19 days

Medium	*F. lini* F 74		*F. orthoceras* var. *apii f.* 1 F 85		Gram wilt fungus F 57		Gram wilt gungus F 92		Gram wilt fungus F 93	
	Surface of Substrate	Mycelium	Surface of Substrate	Mycelium	Surface of Substrate	Mycelium	Surface of Substrate	Mycelium	Surface of Substrate	Mycelium
1	Unchanged .	Lacking . .	Unchanged .	Lacking .	Unchanged	Lacking .	Unchanged	Lacking .	Unchanged	Lacking
2	Do. .	Do. . .	Do. . .	Do. .	Do. .	Do. .	Do. .	Do. .	Do. .	Do.
3	Do. .	Do. . .	Do. . .	Do. .	Do. .	Do. .	Do. .	Do. .	Do. .	Do.
4	Do. .	Do. . .	Do. . .	Do. .	Do. .	Do. .	Do. .	Do. .	Do.	Do.
5	Do. .	White . .	Do. . .	Do. .	Do. .	White .	Do. .	White .	Do. .	White
6	Do. .	Do. . .	Do. . .	Do. .	Do. .	Do. .	Do. .	Do. .	Do. .	Do.
7	Do. .	Do. . .	Do. . .	White .	Do. .	Do. .	Do. .	Do. .	Do. .	Do.
8	Do. .	Do. . .	Do. . .	Do. .	Do. .	Do. .	Do. .	Do. .	Do. .	Lacking
9 (oatmeal)	Dark hyssop violet	White with trace of hyssop violet	White with dark mouse gray at bottom of one tube	Do. .	White .	Do. .	White .	Do. .	White .	White
10 (Plain agar)	Unchanged .	Lacking . .	Unchanged .	Lacking .	Unchanged	Lacking .	Unchanged	Lacking .	Unchanged	Lacking

TABLE XV

Conidia obtained from surface scrapings of synthetic media, plain agar and oatmeal agar after 20—21 days
(Replicate tubes designated a, b, c, d)

Medium	*F. lini* F 74	*F. orthoceras* var. *apii f.* 1 F 85	Gram wilt fungus F 57	Gram wilt fungus F 92	Gram wilt fungus F 93
1	Continuous (rarely 1-sept.), ovoid to spindle-shaped, hyaline, abundant. *a, b, c, d.*	Continuous, ovoid to spindle-shaped, hyaline. Moderately abundant.	Continuous, ovoid to spindle-shaped, hyaline, abundant. *a, b.*	0-2-sept., ovoid to spindle-shaped or slightly curved and bluntly pointed at both ends. Hyaline. Moderately abundant. *a, b.*	Continuous ovoid to spindle-shaped, hyaline, few. Showing a tendency to cluster into false heads. *a, b.*
2	Continuous, ovoid to spindle-shaped, hyaline, abundant. *a, b, c, d.*	Continuous, ovoid to spindle-shaped, hyaline. Moderately abundant.	Continuous or 1-sept., ovoid to spindle-shaped, hyaline, abundant. *a, b.*	0-3-sept., ovoid to spindle-shaped when continuous, spindle-shaped or slightly curved and tapering to a blunt point at both ends when septate. Hyaline. Continuous spores abundant. Septa distinct. Septate spores few. *a, b, c, d.* 3-sept. $35 \cdot 5 \times 3 \cdot 6\mu$	Continuous, ovoid to spindle-shaped, hyaline, abundant. *a, b.*
3	0-3-sept., continuous spores ovoid to spindle-shaped, septate spores spindle-shaped or slightly curved, bluntly pointed at both ends, hyaline, septations fairly distinct. Septate spores in *a* and *b* only, in considerable numbers.	Continuous, ovoid to spindle-shaped, hyaline. Moderately abundant.	Continuous or 1-sept. (one 3-sept. spore observed), ovoid to spindle-shaped, hyaline, abundant.	0-3-sept., ovoid to spindle-shaped when continuous, spindle-shaped or slightly curved and tapering to a blunt point at both ends when septate. Hyaline. Continuous spores abundant. Septa distinct. Septate spores few. *a, b, c, d.* 3-sept. $34 \cdot 7 \times 3 \cdot 5\mu$	Continuous, ovoid to spindle-shaped hyaline, abundant. *a, b.*
4	Continuous, ovoid to spindle-shaped, some spores vacuolated but mostly hyaline. Abundant. *a, b, c, d.*	Continuous ovoid to spindle-shaped, hyaline, abundant.	0-3-sept. (one 4-sept. spore observed), the continuous spores ovoid to spindle-shaped and abundant, the septate ones spindle-shaped or	0-3-sept., ovoid to spindle-shaped when continuous, spindle-shaped or slightly curved and tapering to a blunt point at both ends when septate. Hyaline.	Continuous, ovoid to spindle-shaped, hyaline, abundant. *a, b.*

			slightly curved, tapering to blunt points at both ends, few. Hyaline. *a, b.* 3-sept. 37·5μ × 3·8μ.	Continuous spores abundant, septate spores rare. Septa distinct. *a, b, c, d.* 3-sept. 33·8 × 3·7μ (average of six spores only).	
5	In tubes *a, b, d.* continuous, ovoid to spindle-shaped, vacuolate, abundant. In *c* long spores in great abundance, 0-3 sept., cylindrical or slightly curved, tapering to blunt point at both ends, highly vacuolated, without foot cell. Total of 1195 spores examined consisted of 92·2 per cent 0-sept., 4·5 per cent 1-sept., 0·9 per cent 2-sept., and 2·4 per cent 3-sept. 3-sept. 33·2μ × 4·1μ.	Continuous, ovoid to spindle-shaped, hyaline, few.	Continuous or 1-sept., ovoid to spindle-shaped or slightly curved, hyaline, abundant. *a, b.*	0-3-sept., ovoid to spindle-shaped when continuous, spindle-shaped or slightly curved and tapering to a blunt point at both ends when septate. Hyaline. Continuous spores abundant, septate spores few. Septa distinct. *b.* 3-sept. 34·3 × 3·7μ.	Continuous, ovoid to spindle-shaped, abundant in *b, c* and *d.* In *a*, some (rare) 3-sept. spores, spindle-shaped or slightly curved and tapering to a blunt point at both ends. Septations very indistinct. Vacuolated. 3-sept. 27·8 × 3·4μ.
6	Continuous, ovoid to spindle-shaped, abundant, vacuolated. *a, b, c, d.*	Continuous, ovoid to spindle-shaped, hyaline, moderately abundant.	Continuous or 1-sept. (one 3-sept. spore observed), ovoid to spindle-shaped or slightly curved, hyaline, abundant. *a, b.*	0-3-sept., ovoid to spindle-shaped when continuous, spindle-shaped or slightly curved and tapering to a blunt point at both ends when septate. Hyaline. Continuous spores abundant. Septate spores few. Septa distinct. *a, b, c, d.* 3-sept. 31·1 × 3·8μ.	Continuous, ovoid to spindle-shaped, hyaline, moderately abundant. *a, b.*
7	In *a* and *c*, continuous, ovoid to spindle-shaped, vacuolated, abundant. In *b* and *d*, 3-sept. spores also seen, spindle-shaped or slightly curved, tapering to blunt point at both ends, highly vacuolated, few.	Continuous, ovoid to spindle-shaped, hyaline, few.	Continuous or 1-sept., ovoid to spindle-shaped or slightly curved, hyaline, abundant. *a, b.*	0-3-sept., ovoid to spindle-shaped when continuous, spindle-shaped or slightly curved and tapering to a blunt point at both ends when septate. Hyaline. Continuous spores abundant, septate spores rare. Septa distinct. *a, b, c, d.* 3-sept. 32·7 × 4·0 μ (mean of 4 spores only).	Continuous, or 1-septate ovoid to spindle-shaped, hyaline, abundant. *a, b.*
8	In *b, c* and *d*, continuous, ovoid to spindle-shaped, vacuolated, abundant. In *a*, 3-sept. spores also seen, spindle-shaped or slightly curved, tapering to blunt point at both ends, highly vacuolated, few.	Absent . . .	Continuous, ovoid to spindle-shaped, hyaline, abundant. *a, b.*	Continuous, ovoid to spindle-shaped, hyaline, abundant. *a, b, c, d.*	Continuous or 1-sept., ovoid to spindle-shaped, hyaline, abundant. *a, b.*

TABLE XV—*contd.*

Medium	*F. lini* F 74	*F. orthoceras* var. *apii* f. 1 F 85	Gram wilt fungus F 75	Gram wilt fungus F 92	Gram wilt fungus F 93
9 (Oatmeal agar)	Continuous, ovoid to spindle-shaped, vacuolated, abundant *a, b, c, d.*	Continuous (rarely 1-sept.) ovoid to spindle-shaped, sometimes slightly curved, hyaline, abundant.	Continuous, ovoid to spindle-shaped, hyaline, abundant. *a, b.*	0-3-sept., ovoid to spindle-shaped when continuous, spindle-shaped or slightly curved and tapering to a blunt point at both ends when septate. Hyaline. Continuous spores abundant, septate spores also fairly abundant. Septa distinct. *a, b.* Total of 686 spores examined consisted of 92·7 per cent 0-sept., 4·8 per cent 1-sept., 0·6 per cent 2-sept. and 2·0 per cent 3-sept. 3-sept. 30 × 3·7μ.	Continuous or 1-sept., ovoid to spindle-shaped, hyaline moderately abundant. *a, b.*
10 (Plain agar)	Continuous, ovoid to spindle-shaped, vacuolated, few. *a, b, c, d* (Growth very poor)	Absent (Growth very poor).	Continuous, ovoid to spindle-shaped, hyaline, few. *a, b.* (Growth very poor)	0-1-sept., ovoid to spindle-shaped, hyaline, few. (Growth very poor)	Continuous, ovoid to spindle-shaped, hyaline, few. *a, b.* (Growth very poor).

TABLE XVI

Chlamydospore production on synthetic media, plain agar and oatmeal agar after 21 days (Replicate tubes designated a, b, c, d)

Medium	F 74	F 85	F 57	F 92	F 93
1	Terminal, single, 1-celled, smooth, hyaline. Rare. *a, b, c, d*	Absent . . .	Absent	Absent	Absent
2	Absent . . . . *a, b, c, d*	Terminal and intercallary, single, 1-celled, hyaline, smooth, few.	Terminal, single, 1-celled, smooth, hyaline, few.	Terminal and intercallary, single, 1-celled, smooth, hya-line, rare.	Do.
3	Terminal and intercallary, single, 1-celled. Mostly smooth and hyaline, but sometimes warty and brown. Abundant in *a* and *b* Absent in *c* and *d*	Absent . . .	Terminal and intercallary, single, 1-celled, smooth, hyaline, abundant.	Terminal, single, 1-celled, smooth, hyaline, rare.	Do.
4	Absent . . . . . *a, b, c, d*	Absent	Terminal and intercallary, single, 1-celled, smooth, hyaline, abundant.	Terminal, single, 1-celled, smooth, hyaline, rare.	Do.
5	Absent . . . . . *a, b, c, d*	Terminal, single, 1-celled, smooth, few	Terminal and intercallary, single, 1-celled, smooth, hyaline, abundant.	Terminal and intercallary, single, 1-celled, smooth, hyaline, rare.	Do.
6	Terminal and intercallary, single, 1-celled, smooth, hyaine. Moderately abundant in *b*, rare in *d*, absent in *a* and *c*.	Terminal, single, 1-celled, smooth, hyaline, few	Terminal and intercallary, single, 1-celled, smooth, hyaline, abundant.	Terminal and intercallary, single, 1-celled, smooth, hyaline, moderate numbers.	Do.
7	Absent . . . . . *a, b, c, d*	Absent . . .	Terminal and intercallary, single, 1-celled, smooth, hyaline, few.	Absent . . . . . *a, b.*	Do.
8	Absent . . . . . *a, b, c, d*	Absent . . .	Terminal and intercallary, single, 1-celled, smooth, hyaline, few.	Absent . . . . *a, b.*	Do.
9	Absent . . . . . *a, b, c, d*	Terminal, single, 1-celled, smooth, hyaline, rare	Terminal and intercallary, single, 1-celled, smooth, hyaline, moderately abundant.	Terminal and intercallary, single, 1-celled, smooth, hyaline, abundant.	Do.
10	Absent . . . . . *a, b, c, d*	Absent . . .	Terminal and intercallary, single, 1-celled, smooth, hyaline, abundant.	Terminal and intercallary, single, 1-celled, smooth, hyaline, abundant.	Do.

The section Elegans has a number of characteristics which are said to typify the section. The more important of these are :—

(1) Presence of abundant, mostly one-celled, ovoid to spindle-shaped, small conidia, not borne in chains.
(2) Presence of terminal and intercallary chlamydospores.
(3) Delicate walls and septations in the conidia.

The species in the sub-section Orthocera have the additional characteristics of slenderness of the spores, which are almost straight or spindle-shaped, with a papillate or very slightly foot-celled base. They are without, or at most with traces of sporodochia.

The experiments described here have indicated that the authentic cultures studied produce in many cases abundant small conidia of the kind described. *F. conglutinans* and *F. conglutinans* var. *apii f.* 1 rarely produced any at all. Steamed rice was in many cases unsatisfactory for their production, but the remaining media used, namely oatmeal agar, potato cylinders, two per cent potato dextrose agar and five per cent potato dextrose agar, were about equally satisfactory.

All the cultures were found to produce chlamydospores, but they were found to vary to an extraordinary degree in this respect. *F. orthoceras* var. *longuis*, and the gram wilt fungus F 57 produced chlamydospores very rarely. There was a striking difference between abundance of chlamydospores at 20° C and at 35°C, the latter usually greatly enhancing their production.

The conidia had delicate cell-walls and septations, and this characteristic did not seem to alter with the medium or the temperature. It seems to be a characteristic of the group.

Owing to the fact that some of the cultures failed to produce an appreciable number of 3-septate spores, the ratios of length to breadth were not determined, but in all cases they were spindle-shaped or only slightly curved, and they had no typical foot-celled base. These again appear to be characteristics of the group.

Provided these fungi were grown at 35°C they could readily be identified as *Orthocera-Fusaria* with the possible exception of *F. orthoceras* var. *apii f.* 1, *F. orthoceras* var. *longuis* and the gram wilt fungus F 57, for which a large number of tubes might have to be examined before reaching a final decision.

On the whole, the description of the sub-section given by Wollenweber and Reinking seems to be satisfactory and it covers the degree of variatio exhibited by the different members.

The distinction between the various species depends, as stated previously, on the following major characteristics :—

(1) Presence or absence of pionnotes.
(2) Type of conidiophores.
(3) Colour of stroma.
(4) Type of plectenchyma-erumpent or smooth.
(5) Sizes of conidia.
(6) Pathogenicity.

The type of conidiophore branching is used only for distinguishing *F. bostrycoides*. As stated, no bostrycoid branching could be found; the method of branching of the conidiophores in this species appeared identical with all the other species of the group.

Pathogenicity is a very positive characteristic, but it has not been practical to determine its variability.

According to Wollenweber and Reinking sclerotia may or may not occur in the sub-section. It is a noteworthy fact, however, that of the 12 representatives they describe, sclerotia are stated to be absent in four and no mention is made of them in seven others. The only case where they are mentioned is in *F. lini*, a species which they consider to be, as regards form of macroconidia, a bridge between *F. orthoceras* and *F. oxysporum*. The latter fungus produces sclerotia. No doubt it is very convenient to leave this trying species, *F. lini*, out of the key. It is questionable whether any of the fungi produced any structure which could genuinely be called a ' stroma '. The nearest approach was a plectenchymatous layer, and the fungi differed little in their formation of this. The term ' stroma ' has been used in this paper to describe the thin superficial, fleshly layer which forms on the surface of all moderately nutritious agars. It has not been found to be erumpent.

We are left with three variable characters which might be used as an aid to identification, namely, presence or absence of pionnotes, colour of ' stroma ', and sizes of conidia. What are they worth ?

The only culture definitely producing pionnotes was *F. conglutinans* var. *callistephi*. Four other species, namely *F. orthoceras* var. *apii*, *F. orthoceras* var. *longuis*, *F. angustum* and *F. lini* had very thin superficial layers of spores which were barely entitled to the name ' pionnotes ', and could best be described in Wollenweber and Reinking's words ' Konidienschleime von geringer Ausdehnung '. It so happens that *F. congulutinans* var. *callistephi* is placed by Wollenweber and Reinking in the group with pionnotes typically absent, though in their detailed description they say that the conidia of this variety are more or less copiously scattered about, in exceptional cases covering the substrate as a faint, thin transitory pionnotes.

The colours of ' stroma ' or of surface of the substrate lend themselves better than many characters to accurate description because they can be compared with well-known colour standards. It has been clearly shown that there were three main groups in the cultures studied, based on pigmentation. These groups may be compared with the colours described by Wollenweber and Reinking :—

Culture	Colour of ' stroma ' or surface of substrate	Colour of stroma according to Wollenweber and Reinking
F. orthoceras var. *pisi*	Blue-brown-hued . .	Reddish ochre to chestnut-brown
F. bostrycoides . .	Purple hued, changing to red in HCl and blue or violet in KOH	Brownish white, then palm-green or violet
F. orthoceras . .	Ditto . . .	Pale, flesh-coloured, green-flecked, purple-red-violet (becoming blue in alkali)

Culture	Colour of 'stroma' or surface of substrate	Colour of stroma according to Wollenweber and Reinking
F. orthoceras var. *apii*	Purple hued, changing to red in HCl and blue or violet in KOH	Pale, flesh-coloured, greeno flecked, purple-red-violet- (becoming blue in alkali)
F. orthoceras var. *longuis*	Ditto . . .	Ditto.
F. angustum . .	Ditto . . .	Rose to purple-red (becoming blue in alkali)
F. lini . . .	Ditto . . .	Various coloured, clear, brownish white, flesh coloured, greenish, rose to red (in alkali violet or blue)
F. orthoceras var. *apii f.* 1	Usually non-pigmented, sometimes variously grayish-purple	Pale, not becoming reddish-violet on rice mush nor blue in alkali
F. conglutinans . .	Non-pigmented . .	Pale, white, then brownish to rosy white
F. conglutinans var. *betae*	Non-pigmented . .	Pale, white, then brownish to rosy white
F. conglutinans var. *callistephi*	Ditto . . .	Pale, white, then yellowish, brownish to rosy-white, in exceptional cases with traces of grayish lilac colour
F 57 Gram wilt organism	Usually non-pigmented, sometimes variously grayish-purple	....
F 92 Gram wilt organism	Ditto	....
F 93 Gram wilt organism	Ditto .	....

The case of *F. orthoceras* var. *apii f.* 1 throws considerable light on the whole question of pigmentation. According to Nelson, Coons and Cochran [1937] this fungus is supposed to produce no pigmentation. It is clearly shown that it may produce it under certain conditions, and the pigment shows the usual acid and alkali reactions.

Apart from *F. orthoceras* var. *pisi* there is only one significant pigment produced, namely the purple pigment becoming red in hydrochloric acid and blue or violet in potassium hydroxide. That certain isolates of *F. orthoceras* var. *pisi* may also produce this pigment is suggested by the work of Snyder [1933].

The remaining characteristic which lends itself to accurate measurement is spore size. It has been shown that as regards the 0-septate spores the variation within so-called species is as great as or greater than the variation between species, and the character is therefore of no value for specific determination,

Sizes of 3-septate spores could not in many cases be determined owing to the fact that some cultures produced few or no such spores. In the case of *F. lini* comparisons may be made with the figures of Wollenweber and Reinking :—

Culture	Measurements by Wollenweber and Reinking	Author's measurements
F. lini . . .	35×4 (21–41×2·5–4·5) .	On Brown's medium with 0·05 per cent asparagine (25 spores), 33·2×4·1μ (18·7–51·0×3·4–5·8) On 3 per cent oatmeal agar at 20° C (4 spores only) 46·3μ in length (39·1–52·7)

It is clear that in *F. lini* the variation is much greater than indicated by Wollenweber and Reinking.

The three gram-wilt organisms F 57, F 92 and F 93, though alike in lack of colour, show marked differences in regard to spore production. F 57 and F 93 produce very few 3-septate spores, but when they do produce them they are not appreciably different in size, and the range of variation of the means is not greater than that of *F. lini*. Spores of similar septations are alike in the three isolates as regards form. Duplicate tubes of these and of other cultures vary greatly in the ratios of continuous to septate spores. All the three gram-wilt organisms can produce chlamydospores, but in abundance of these they differ.

We are forced to the conclusion that the cultures of *Orthocera-Fusaria* maintained at Baarn cannot, with one or two exceptions, be recognized from the descriptions given by Wollenweber and Reinking. The key simply falls to the ground when used with authentic cultures.

According to Wollenweber and Reinking, *Fusarium lini* fruits better than the other species of this section, and in many isolations even produces occasional sporodochia, and therefore belongs to a transitional form with the other groups. This view is strengthened by their statement that the macroconidia are, in form, a bridge between *F. orthoceras* and *F. oxysporum*. The original description of *F. lini* given by Bolley [1901] definitely refers to sporodochia with typically 4-celled conidia. If we are to include the other fungi in this species it means that we are practically obliged to regard them as only subnormal material of *Oxysporum*—or *Constrictum-Fusaria*, a procedure which Wollenweber and Reinking [1935] give reasons for not adopting.

F. angustum, according to the original description by Sherbakoff [1915] differs from *F. orthoceras* and *F. conglutinans*, in its spore form narrowly tapering at the ends and sometimes anguiform. The lack of septate spores in the experiments described here have made it impossible to study the reliability of this character. A study of the original description makes one wonder why this fungus was ever placed in the sub-section Orthocera. The shape of spores pictured by Sherbakoff, with their narrowly tapering ends and their distinct

foot-cells, together with the high length : breadth ratio, would seem to eliminate it completely from this sub-section, and bring it in line with the *Constrictum-Fusaria*. Wollenweber and Reinking [1935] have retained it in the sub-section Orthocera in spite of a length : breadth ratio of 13 : 1, which is quite outside the limits of the group.

F. bostrycoides has not in any of the observations made shown the bostrycoid branching by which it is supposed to be recognizable and from which it has taken its name. It has, however, a very distinct tendency to produce conidia in false heads. For the time being it seems advisable to retain this species, though eventually it may have to undergo union with one of the others.

We are left with *Fusarium orthoceras* and *F. conglutinans*. It has been suggested by Wollenweber and Reinking [1935] that these two might be united, but it has not been done because the fungi grew somewhat differently. In the experiments described here, however, all distinctions have completely broken down. In many respects the differences between varieties within one of these species are greater than the differences between the two species, and all efforts have failed to reveal a characteristic difference between the so-called species. It seems that we are fully justified in uniting the two under the name *Fusarium orthoceras* App. and Wollenweber.

Fusarium conglutinans was the name given by Wollenweber [1913] for the fungus causing wilt disease of cabbage. The description was as follows :—

'Differs from *F. orthoceras* in the absence of a wine-red colour on rice, which is a striking character of typical species of the section Elegans. Vascular parasite, cause of wilt disease of *Brassica oleracea* var. *capitata* (proved by Erwin F. Smith, L. R. Jones and L. L. Harter) in the United States of America.'

It will be seen that the difference lies only in pigment production. Yet Wollenweber and Reinking mention a rosy-white colour in *F. conglutinans* and *F. conglutinans* var. *callistephi*, and conversely, as we have seen, non-pigmented strains are found in varieties of *F. orthoceras*. If this were accepted as the significant difference between the two species, one wonders why Wollenweber and Reinking placed *F. apii* var. *pallens* of Nelson and Cochran (*F. apii* var. *palliidum* Nelson and Sherbakoff) as a variety of *F. orthoceras* and not of *F. conglutinans*. The answer, of course, is that there is no fundamental difference between the species.

Fortunately, *F. orthoceras* is one of the species of *Fusarium* which at the start had an adequate description [Appel and Wollenweber, 1910]. This certainly cannot be said of *F. conglutinans*. The original description of *F. orthoceras* covers the description of *F. conglutinans* and its varieties *betae* and *callistephi*, apart from the characters of pathogenicity. It is therefore proposed to rename these three fungi as follows :—

Fusarium orthoceras App. et Wollr. var. *conglutinans* n.c.
Syn. *F. conglutinans* Wr.

Morphologically indistinguishable from the fundamental species. Cause of a vascular wilt disease of *Brassica oleracea* in North America (U. S. A.).

Fusarium orthoceras App. et Wollr. var. *betae* n.c.
Syn. *F. conglutinans* Wr. var. *betae* Stewart.

Morphologically indistinguishable from the fundamental species. Cause of a seedling blight of *Beta vulgaris* in North America (U. S. A.).

Fusarium orthoceras App. et Wollr. var. *callistephi* n.c.
Syn. *F. conglutinans* var. *majus* Wr.

F. conglutinans Wr. var. *callistephi* Beach.

Morphologically indistinguishable from the fundamental species. Cause of a vascular wilt disease of *Callistephus chinensis* in most countries where this plant is grown.

The gram wilt fungi are considered to comprise one variety :—

Fusarium orthoceras App. et Wr. var. *ciceri* n. var. Morphologically indistinguishable from the fundamental species. Cause of a vascular wilt disease of *Cicer arietinum* in India.

In the opinion of the author, the decision of Nelson, Coons and Cochran [1937] to change the names of *Fusarium orthoceras* var. *apii* Woll. et Rkg. and *F. orthoceras* var. *apii f.* 1 Woll. and Rkg. to Fusarium *apii* and *F. apii* var. *pallidum* respectively is unfortunate. The decision was based not on experimental evidence that the fungi concerned are morphologically different from *F. orthoceras* but on the opinion that pathogenic considerations should be a major criterion in distinguishing species—'The most important differential character is the distinct host relationship and it is chiefly on this basis that the segregation is made.' When Linford in 1928 created the variety *pisi* of *F. orthoceras* based on the ability of this fungus to cause a wilt of *Pisum* he laid the foundations of a nomenclatorial system for these fungi which was already of proved worth in *Puccinia graminis* with its varieties. Linford's procedure appears to be the one most likely to avoid confusion.

Summary

(1) Morphological and cultural studies have been made of eleven of the twelve species, varieties or physiologic forms of *Fusarium* of the sub-section *Orthocera*, using cultures supplied by the Centraalbureau voor Schimmelcultures, Baarn. *Fusarium conglutinans* var. *citrinum* Wr. (*F. citrinum* Wr.), the remaining species, could not be obtained. Included in the experiments were three fungi able to cause wilt of gram (*Cicer arietinum*).

(2) The cultures vary in ability to produce spores in the aerial mycelium, to produce septate spores, to produce chalmydospores, to produce pigments etc.

(3) In respect of pigment production, the cultures fall in three groups :—

(i) Producing blue or brown pigments, unaffected by addition of hydrochloric acid or potassium hydroxide.

(ii) Producing a purple pigment, becoming red in hydrochloric acid and blue or violet in potassium hydroxide.

(iii) Non-pigmented.

While all cultures of *F. conglutinans* failed to produce pigments, varieties or forms of *F. orthoceras* fell within all three groups. Steamed rice is an excellent medium for studying pigment production.

(iv) Production of aerial mycelium, and of a so-called ' stroma ', and size of non-septate spores are of no value in identifying these species.

(v) Pigment production appeared not to be appreciably influenced by temperature of growth except with *F. orthoceras* var. *apii f.* 1 Woll., a fungus reported to be non-pigmented, but producing the purple pigment in some cultures at 20° and 25° C.

(vi) The only culture producing typical pionnotes was *F. conglutinans* var. *callistephi* which is placed by Wollenweber and Reinking in the group with pionnotes typically absent.

(vii) The effect of temperature on either the number of septations or the length of conidia was slight, but a temperature of 35° C was markedly more favourable for chlamydospore production than one of 20° C.

(viii) An experiment on the effect of asparagine in a synthetic medium on the septation or length of spores were inconclusive and it was found that replicate cultures often gave entirely different results.

(ix) The results are discussed in detail and reasons are given for regarding *Fusarium conglutinans* as a synonym of *F. orthoceras*, which should be divided up into varieties based on major pathogenic capabilities. Reasons are given for not uniting *F. orthoceras* with the earlier *F. lini* or with *F. bostrycoides* or *F. angustum*. It is not clear, in fact, why *F. angustum* should be placed in the sub-section Orthocera at all.

(x) *F. conglutinans*, *F. conglutinans* var. *betae*, and *F. conglutinans* var. *callistephi*, become varieties of *F. orthoceras*, and the new variety *F. orthoceras* var. *ciceri* is proposed.

The author acknowledges his deep appreciation of help rendered by Mr. H. H. Prasad in maintaining cultures, preparing media, and in many other ways. Thanks are due also to Dr. B. B. Mundkur for kindly making available for use his personal collection of reprints.

REFERENCES

Appel, O. and Wollenweber, H. W. (1910). *Arb. biol. Anst., (Berl.)* **8**, 1-207

Bolley, H. L. (1901). *North Dakota Agric. Coll. Bull.* **50**

Brown, W. (1925). *Ann. Bot.* **39**, 373-408

Linford, M. B. (1928). *Univ. Wis. Agric. Exp. Sta. Res. Bull.* **85**

Nelson, R., Coons, G. H. and Cochran, L. C. (1937). *Michigan Agric. Exp. Sta. Tech. Bull.* **155**

Prasad, N. and Padwick, G. W. (1939). *Ind. J. Agric. Sci.* **9**, 371-80

Ridgway, R. (1912). *Colour Standards and Colour Nomenclature.* Washington

Sherbakoff, C. D. (1915). *Cornell Agric. Exp. Sta. Mem.* **6**

Snyder, W. C. (1933). *J. Agric. Res.* **47**, 65-88

Wollenweber, H. W. (1913). *Phytopath.* **3**, 24-50

Wollenweber, H. W. and Reinking, O. A. (1935). *Die Fusarien, ihre Beschreibung, Schadwirkung und Bekampfung* : Berlin, Paul Parey

Wollenweber, H. W.; Sherbakoff, C. D.; Reinking, O. A.; Johann, H. and Bailey, A. A. (1925). *J. Agric. Res.* **30**, 833-43

CYTOLOGICAL STUDIES IN *GOSSYPIUM*

I. CHROMOSOME BEHAVIOUR IN THE INTERSPECIFIC HYBRID *G. ARBOREUM* × *G. STOCKSII*

BY

P. ABRAHAM, B.A., M.Sc.

Agricultural Research Institute, Coimbatore

(Received for publication on 9 August 1939)

(With 13 text-figures)

INTRODUCTION

WITH the object of transferring the drought-resistant qualities of the Asiatic wild cotton *G. Stocksii* Mast. to the strains of rain fed cultivated cottons of southern India, hybridization between them was attempted by the Cotton Specialist, Coimbatore. The hybrids between the local Karunganni strain K1 (*G. arboreum* L. var. *neglectum* Watt forma *indica* H. & G.) ($2n=26$) and *G. Stocksii* Mast. ($2n=26$), proved to be completely sterile. A cytological examination of the hybrid was undertaken to discover the causes of its sterility.

Meiosis in similar hybrids between *G. Stocksii* Mast. and other types of *G. arboreum* L. have been examined by Skovsted [1937].

MATERIAL AND METHODS

All the seeds and plant material required for the investigation were kindly supplied by Rao Bahadur V. Ramanatha Ayyar, Cotton Specialist, Coimbatore. Flower buds for the study of meiosis were collected from plants which were grown at the Cotton Breeding Station and at the Imperial Sugarcane Breeding Station, Coimbatore.

Flower buds were fixed in acetic alcohol for 24 hours, washed in 90 per cent alcohol and then dehydrated and infiltrated by the chloroform method [La Cour, 1931]. A thickness of 18 to 20μ was found necessary for anther sections. Slides stained in gentian violet gave good results.

Temporary aceto-carmine mounts of either fresh or fixed material were made according to the method suggested by Bellings [1926] and used for microscopic examination and drawings. Such temporary mounts, after being ringed, were quite suitable for critical examination and fit for use for nearly five to seven days. A good number of drawings of meiotic stages reproduced in this paper were made from such temporary mounts.

MEIOSIS IN THE PARENTS

Chromosome pairing and chiasma behaviour have been studied in both the parents at diplotene, diakinesis and metaphase stages and the data are

presented in Table I and II$_a^r$(Appendix). To ensure accuracy in determinations observations were made on 78 bivalents at each stage in both the species, confining observations only to uncut nuclei showing complete complement of chromosomes.

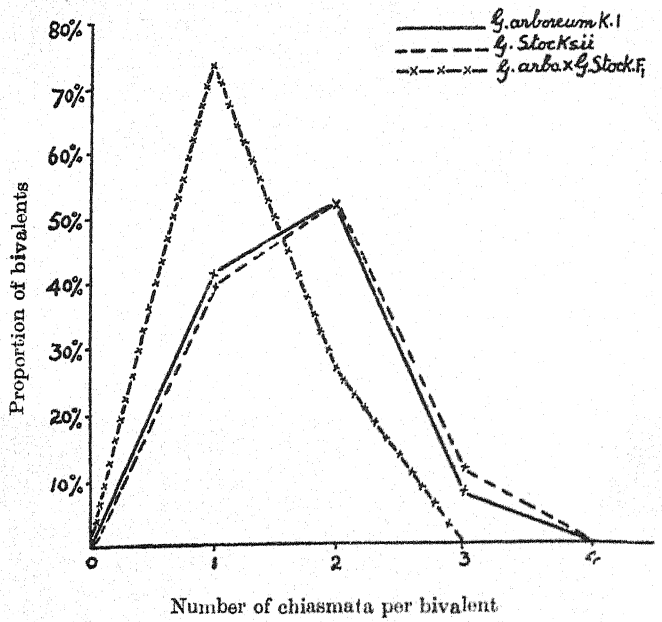


FIG. 1. Curves showing the chiasma frequency per bivalent in the two parents and the hybrid

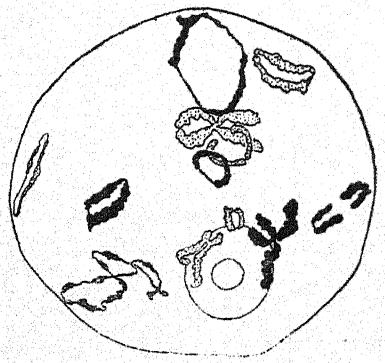


FIG. 2. Diplotene stage in *G. arboreum* K1 (×1000)

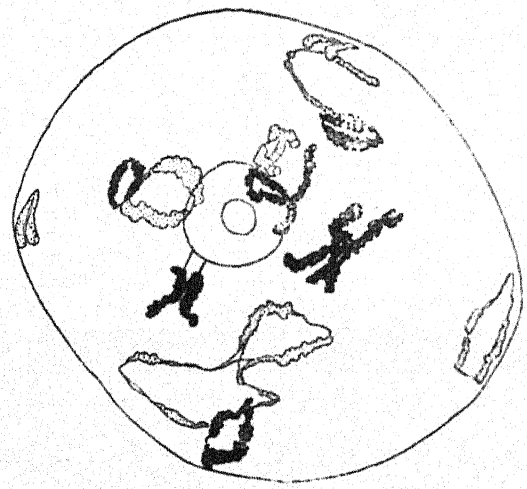


FIG. 3. Diplotene stage in *G. Stocksii*. (×2100)

The following observations have been recorded :

The number of chiasmata in each bivalent varied from one to three in both the species, two being most common. V—, X—, O—, and 8-shaped bivalents were observed (Figs. 2 and 3). Except for slight variations from nucleus to nucleus, the general appearance and configurations of the bivalents at the same stage were nearly the same in both the species. The mean chiasmata per bivalent at diplotene was nearly 1·7 in both the species. Terminalization of chiasmata was incomplete in both the species. There was increase in the coefficient of terminalization from diplotene to metaphase (Tables I and II and Fig. 1). Between diplotene and diakinesis stages there was very little reduction of the mean chiasmata per bivalent, whereas there was a definite reduction between diakinesis and metaphase. Differential contraction of chromosomes has been observed at diplotene in both the species, some bivalents having shortened and thickened more rapidly than others (Figs. 2 and 3).

The first and second meiotic divisions have been found to be quite normal giving rise to normal tetrads and pollen grains.

Meiosis in the hybrid

In the sterile F_1 hybrid between the two species also, observations were made in the stages from dipoltene to metaphase. Just as in the case of the parents, six complete nuclei showing all the bivalent and univalent chromosomes were selected for observations at each stage. The number of bivalents in a nucleus was seen to vary from five to nine, the average number per nucleus being nearly seven. The rest of the chromosomes remained as univalents (Figs. 5 and 6). The number of chiasmata in a bivalent varied from one to two only, the majority having only a single chiasma (Figs. 4 and 1). The mean chiasmata per bivalent at diplotene was, therefore, only 1·3 which was considerably less than that in the parents. This indicated that the affinity even among the pairing chromosomes in the hybrid was less than that in the parents. V—, X—, O—, and ♂—shaped bilavents could be seen. Terminalization of chiasmata in the bivalents was incomplete as in the parents (Fig. 1 and Table III), but the reduction of the mean chiasmata per bivalent due to terminalization was gradual. The terminalization coefficients at the three stages were lower than those in the parents (Fig. 1 and Table III).

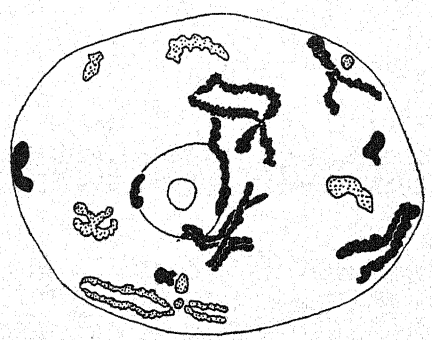


Fig. 4. Diplotene stage in *G. arboreum* K1 × *G. Stocksii* F_1 (×1000)



FIG. 5. Meiotic metaphase stage in the hybrid showing bivalents and univalents. (×2100)

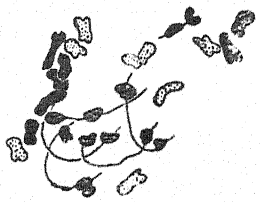


FIG. 6. Anaphase (meiotic) in the hybrid showing arc-shaped chromatic threads (×1000)

In the large number of pollen mother cells examined, no configurations higher than bivalents could be seen. The numbers of bivalents were determined in 24 pollen mother cells which gave an average of 7·13 per pollen mother cell. The details are given in the following table.

Frequency of different combinations of chromosome configurations

No. of different combinations found	Chromosome configurations		No. of pollen mother cells
	Univalents	Bivalents	
1	16	5	1
2	14	6	4
3	12	7	11
4	10	8	7
5	8	9	1

Total of univalents	282
Total of bivalents	171
Mean number of univalents	11·75
Mean number of bivalents	7·13

As is usual in many sterile interspecific hybrids, at metaphase, the bivalents and the univalents were seen scattered about at random in the cytoplasm (Fig. 5). This irregular arrangement was due to the fact that all the chromosomes have not reached the equatorial plate and arranged themselves in the normal compact manner. Although most of the bivalents arranged themselves at the equatorial plate, very often a few of them were seen away from the plate, scattered about in the cytoplasm along with the univalents (Figs. 6 and 7). When the paired chromosomes began to separate and an anaphase spindle was formed, the univalents were seen distributed at random on the spindle (Fig. 8). The fate of the univalents during this division was decided by their position in relation to the separating bivalents. Those situated far away from the equator moved with the daughter bivalents passing to the nearest pole, while those situated in or near about the equatorial plate scattered in the cytoplasm, either in groups or singly, without undergoing any division at first metaphase (i.e. predivision). Such irregular movements of the univalents relative to those of the bivalents that divided gave rise to various kinds of abnormalities in the grouping of the chromosomes at the end of the first division. Besides the two main groups of chromosomes, those that were extruded from the daughter nuclei into the cytoplasm were generally seen scattered singly or in groups of varying numbers (Fig. 11). Occasionally, however, certain pollen-mother-cells showed two distinct compact second metaphase plates (Fig. 12) with unequal numbers of chromosomes.



FIG. 7. Anaphase (meotic) in the hybrid showing separating bivalents connected by chromatic threads. Notice the non-parallel chromatic threads. (×1000)

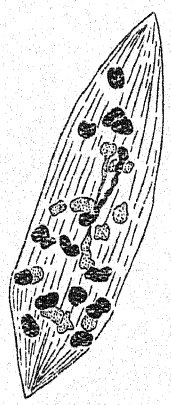


FIG. 8. Anaphase (meotic) in the hybrid showing a regular spindle. (×2100)

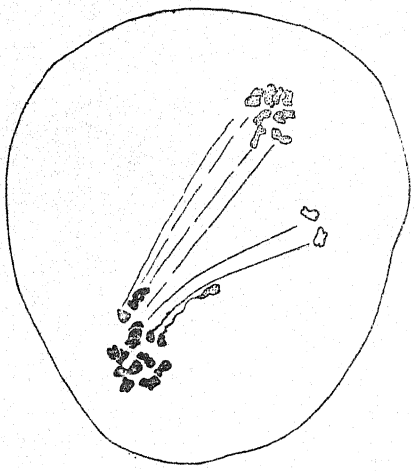


FIG. 9. Pollen mother cells showing anaphases of Division 1 in the hybrid. Notice the division of one of the poles into two. (×1000)

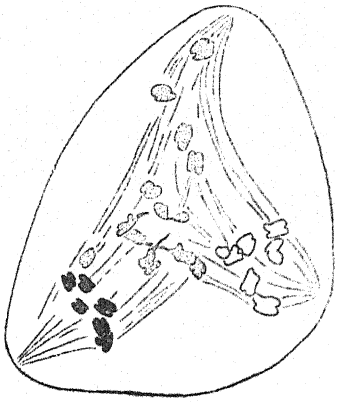
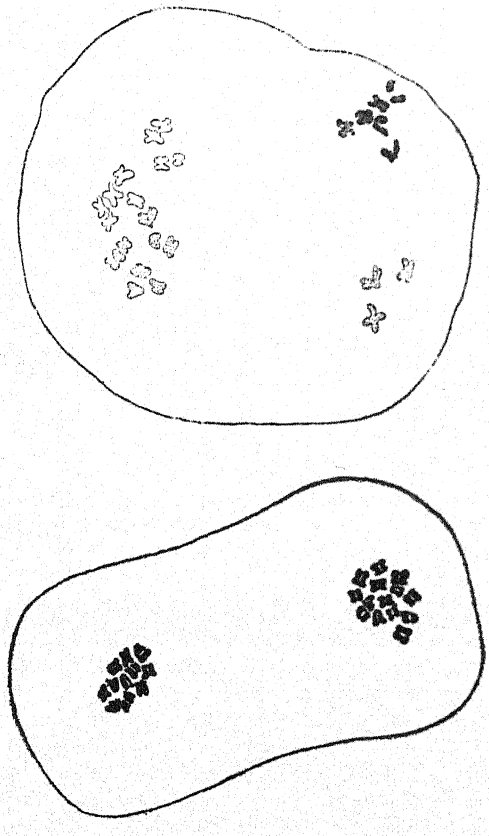


FIG. 10. Pollen mother cell of the hybrid showing a tripolar spindle at Division 1. (×2100)



FIGS. 11 and 12. Pollen mother cells of the hybrid showing second metaphase plates. (×1000)

The abnormal anaphase movements of the chromosomes mentioned above have been found to be associated with various irregularities of the first division spindle. In many pollen mother cells, although the univalents were scattered at random at anaphase, the spindle was straight and bipolar (Fig. 8) like the normal spindles of the parents. In most of the pollen mother cells, the separating daughter bivalents, although sufficiently far away from each other, appeared to be connected by slender chromatin threads (Figs. 6 and 7). The unwinding spirals of the chromatin threads, as a result of the pulling force could be clearly seen. The bivalents were evidently under a constant stress of the pulling force, which naturally caused pulling out of the non-separated parts of the chromatin threads. Some of the cells showed the chromatin threads connecting the separating bivalents, bent in the form of arcs (Fig. 6). The direction of the pull indicated the orientation of the spindle threads and showed that the spindle threads also were of the same arc-shape, as if both the poles were situated on the same side of the cell. Tripolar spindles were also observed in some pollen-mother-cells (Fig. 10). In others a division has been found to occur at one of the two poles (Fig. 9). This has given rise to three main second metaphase plates with a few chromosomes extruded into the cytoplasm either singly or in groups.

As has been shown above, these abnormalities of the first division left the chromosomes scattered in several groups or singly (Fig. 11), and each of these groups or solitary chromosomes formed a second metaphase plate. The number of such plates were seen to vary from two to six. The chromosomes of these second metaphase plates were either univalents, daughter bivalents, or even undivided bivalents, which were all capable of division at this stage. The second division spindles were, therefore, seen to be normal (Fig. 13) in all the pollen-mother-cell examined. The second metaphase plates which contained a small number of chromosomes divided, giving rise to micronuclei and micropollen grains. Occasionally, a plate which contained only a single chromosome, remained undivided (Fig. 13) giving rise to a micropollen grain with a single diad chromosome. Thus it is seen that the pollen grains produced were without the normal complement of chromosomes. In a total of 194 pollen-mother-cells examined, the number of pollen grains produced by a pollen-mother-cell have been found to vary from three to eleven.

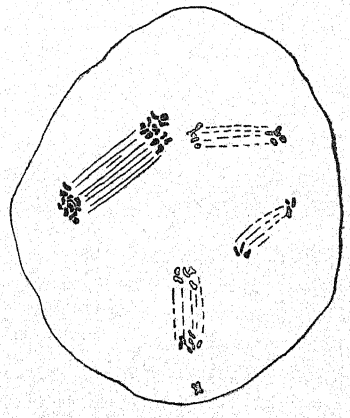


FIG. 13. A pollen mother cell of the hybrid showing second division spindles. See the solitary undivided diad chromosome. (×1250)

Discussion

Causes of sterility

It is evident from the observations made that sterility in this hybrid is due mainly to incomplete pairing of chromosomes at meiosis, as was observed by Skovsted [1935, 1937] in similar interspecific hybrids between these two species and other hybrids among Asiatic cottons. Such failure of pairing is generally caused by lack of homology of various degrees between the chromosomes of the two species involved. Absence of homology in the present instances may be attributed to loss of homology of the chromosomes of the two species as a result of geographical isolation for long periods and their consequent independent evolution, as suggested also by Skovsted [1935, 1937]. The degree of incompatability brought about in the genoms of the two species by such divergent evolutions was vividly shown by the abnormal meiotic behaviour of the chromosomes in the hybrid. As mentioned above, these abnormalities have been found to be closely associated with irregularities in the development of the spindle. According to Darlington and Thomas [1937], a normal spindle is developed by the coordinate action of two agents in the cell, one outside the nucleus and the other inside the nucleus and, therefore, a defective spindle may arise from ' faults ' in the ' mutual adjustment ' of the two agents. The extra nuclear agents responsible for spindle development in plants, according to these authors, correspond in function to the centrosomes found in animals and some lower plants, but are of a different character in that they may ' be supposed to exist as diffused particles which coalesce or congregate at the moment when spindle poles are normally formed '. On the other hand the internal agent is the coordinated action of the centromeres of the dividing chromosomes. ' It seems that to prevent the spindle stretching and bending it is necessary not only to have paired chromosomes, but also to have them there at the right time ' [Darlington, 1937]. Therefore, it follows that variations in the irregularities of the spindle may depend also on the varying numbers of paired chromosomes present. It has been shown that in many of the pollen mother cells of the present hybrid the spindle was straight and bipolar (Fig. 8) like the normal spindles of the parents. It was quite likely that in such cells, the number of bivalents were proportionately high and the majority of them reached the equatorial region in time, formed a regular plate and then separted more or less at the same time, thus controlling the development of the regular spindle. In cells where the number of paired chromosomes ready to divide were comparatively at a minimum, i.e. five or six, the spindle had a tendency to bend in the form of arcs (Fig. 6). This was perhaps due to lack of pairing or to ' the spindle developing too early in relation to the chrosomes ' [Darlington, 1937]. Such bent spindles have been observed in many other organisms also e.g. *Drosophila* [Koller, 1934], *Impatiens* [Smith, 1935]. It was mentioned that in a large majority of the polen-mother-cells, at first anaphase, the separating bivalents, although sufficiently far away from each other, appeared to be still connected by chromatin threads. This non-separation of the chromatin threads for a long time, in spite of the influence of the spindle on the anaphase movement of the daughter bivalents, may probably have been due to the fact that the

spindle began its action in the process of division before the bivalents were ready to separate, and that may have naturally caused pulling out of the non-separated parts of the chromatin threads. The formation of tripolar spindles was also among the abnormalities observed (Figs. 9 and 11). This may be attributed to the ' congregation or coalescence ' of the pole determining material (external agent) in more than two regions, as shown by Darlington and Thomas [1937] in a *Festuca-Lolium* derivative. Even this ' congregation or colalescence ' at a certain pole may sometimes be rather diffuse as was indicated by the non-parallel spindle threads in certain pollen-mother-cells (Fig. 7). All these irregularities of cell division at once indicate a probable fault in the timing adjustment of the two agents responsible for spindle development. Besides loss of homology between their chromosomes, each of the two parents of this hybrid may have, by their divergent evolution, acquired different characteristics and different timings in the various stages of cell division. When they are brought together in hybridity naturally a certain amount of disagreement may occur in the timings of the various stages of cell division as indicated in the observations made. This kind of timing unbalance in the movements of the chromosomes of the hybrid was observed even at the prophase stages. It has been mentioned already that in the parents themselves, there was a certain amount of differential condensation of the chromosomes at the diplotene stage and that such differences could not be observed at diakinesis and later stages. In the hybrid, however, differential condensation of the chromosomes was very marked and persisted even up to the diakinesis stage. It may be due to this timing unbalance among the chromosomes of the hybrid that some of the paired chromosomes at metaphase were not ready to come to the equatorial plate for division (Figs. 6 and 7), and it may be the same disharmony that enhanced the abnormalities of the spindle.

Inter-relationship

It has been shown that out of the 13 pairs of chromosomes of the two parents, *G. arboreum*-K1 and *G. Stocksii* Mast., only about seven pairs (i.e. nearly half) are homologous, while the other six chromosomes appear to be non-homologous. Skovsted's work [1937] has indicated that chromosome homology of some degree exists in all the interspecific hybrids studied. This has led him to think that all the cottons concerned are of monophyletic origin. From the point of view of chromosome homology he has further shown that *G. Stocksii* Mast. is less related to the Old World cottons than the other wild cottons, *G. Sturtii* F. M. and *G. anomalum* Wawra and Peyr. When hybrids between Old World cultivated cottons and the wild cottons, *G. anomalum* Wawra and Peyr. and *G. Sturtii* F. M., show bivalents varying from 9·5 to 11·85, the hybrids between *G. Stocksii* Mast. and the Old World cultivated cottons show bivalents varying from only 3·2 to 7·05 [Skovsted, 1937]. Moreover, the former set of hybrids show a few trivalents and quadrivalents, whereas the latter set do not seem to show any configurations higher than bivalents. In the present hybrid also the average number of bivalents per pollen-mother-cell does not exceed 7·13, and there appears to be no evidence of any autosyndesis taking place. These evidences seem to indicate a distinct difference between *G. Stocksii* Mast. and the other two Old World wild cottons in their

relationships with the Old World cultivated cottons. In this connexion special attention may be drawn to the fact that in all the hybrids of which *G. Stocksii* Mast. is one of the parents, on an averge, not more than about seven pairs of chromosomes seem to be homologous. It may, therefore, follow that the remaining (i.e. six pairs) chromosomes of this species, which do not pair with the chromosomes of the other Old World cottons, might have originated from a source entirely different from the source from which the corresponding set of chromosomes in the other Old World cottons have arisen. Davie [1933] and Skovsted [1937], basing their evidence on secondary pairing of chromosomes, have suggested, that the 26 chromosomes condition of the diploid cottons represent a secondary condition derived from a lower ancestral number. The morphological distinction between the two pairs of satellited chromosomes of the somatic complements of these two species, pointed out by the author [Abraham 1940], also lend support to this view. If this is the real state of affairs, then it may be suggested, in view of the evidence from chromosome pairing given above, that the 26 chromosomes conditions of *G. Stocksii* Mast. was derived, from a lower number of six or seven chromosomes, by a method different from that by which the other species have derived it. Further cytological studies on the inter-relationships among Old World cottons might clear up this issue.

Summary

1. In the two cottons, *G. arboreum* L. var. *neglectum* Watt, forma *indica* H. & G.—strain K1 and *G. Stocksii* Mast., the first and second meiotic divisions were found to be normal.

2. The mean chiasmata per bivalent at diplotene was nearly 1·7 in both.

3. The reduction of the mean chiasmata per bivalent due to terminalization between diplotene and diakinesis was slight (0·03 in *arboreum* and nil in *Stocksii*), whereas there was a considerable reduction between diakinesis and metaphase (0·08 in *arboreum* and 0·10 in *Stocksii*).

4. In the hybrid chromosome pairing was incomplete, the number of bivalents in a nucleus varying from five to nine with an average of 7·13.

5. The mean chiasmata per bivalent at diplotene was only 1·3 and the reduction of the mean chiasmata per bivalent due to terminalization was gradual.

6. The anaphase movements of the chromosomes and the development of the first division spindle in the hybrid were found to be highly irregular.

7. Besides normal spindles, tripolar and bent spindles have been observed.

8. Sterility in the hybrid is found to be the result of the irregularities of cell division, caused by incomplete pairing of chromosomes at meiosis.

9. It is likely that irregularities in cell division may be caused also by differences in the timings of the various stages of cell division acquired by the parent species as a result of their divergent evolution.

10. In all crosses between *G. Stocksii* Mast. and other Old World cottons so far examined, not more than about seven chromosomes of the two species were found to be homologous. This suggests that the remaining six chromosomes of *G. Stocksii* Mast. have had an origin entirely different from that of the corresponding set in other Old World cottons.

ACKNOWLEDGEMENTS

This investigation formed part of the work done by me as a research scholar of the Indian Central Cotton Committee, under Dr E. K. Janaki Ammal, M.A., D.Sc., Geneticist, Imperial Sugarcane Breeding Station, Coimbatore, whom I wish to thank for guidance and help.

I also wish to thank the Indian Central Cotton Committee for the award of a training grant, and the Government Sugarcane Expert, Coimbatore, for giving me the facilities for working at the station.

REFERENCES

Abraham, P. (1940). *Ind. J. Agric. Sci.* **10**, 299

Bellings, J. (1926). *Biol. Bull.* **50**, 160

Darlington, C. D. (1937). *Recent Advances in Cytology.* 2nd Edn. London. J. & A. Churchill Ltd.

Darlington, C. D. and Thomas, P. T. (1937). *Ann. Bot.* **1**, 747

Davie, J. H. (1933). *J. Gen.* **28**, 33

Koller, P. C. (1934). *Proc. Roy. Soc., Edin.* **54**, 67

La-cour, L. (1931). *J. Roy. Micro. Soc.* **51**, 119

Skovsted, A. (1935). *J. Gen.* **30**, 397

——————— (1937). *J. Gen.* **34**, 97

Smith, F. H. (1935). *Cytologia* **6**, 165

Appendix

TABLE I

Summary of observations of chiasma behaviour

G. arboreum—K1

	Diplotene	Diakinesis	Metaphase
1 *Nos. of chiasmata*			
Total	130	128	122
Interstitial	29	19	15
Terminal	101	109	107
Terminalization coefficient . .	0·777	0·825	0·877

Appendix—*contd.*

TABLE I—*contd.*

	Diplotene	Diakinesis	Metaphase
1a *Nos. of chiasmata per bivalent*			
Total	1·66	1·64	1·56
Interstitial	0·37	0·24	0·19
Terminal	1·29	1·40	1·37
2 *Nos. of bivalents with*			
1-chiasma	32	30	34
per cent	41·0	38·4	43·6
2-chiasmata	40	46	44
per cent	51·3	59·0	56·4
3-chiasmata	6	2	..
per cent	7·7	2·6	..
3 *Terminalization coefficient*			
1-chiasma	0·656	0·667	0·618
2-chiasmata	0·875	0·935	0·977
3-chiassmata	0·556	0·500	..

Appendix—*contd.*

TABLE II

Summary of observations of chiasma behaviour

G. Stocksii

	Diplotene	Diakinesis	Metaphase
1 *Nos. of chiasmata*			
Total	132	132	124
Interstitial	33	24	23
Terminal	99	108	101
Terminalization coefficient	0·750	0·818	0·815
1a *Nos. of chiasmata per bivalent*			
Total	1·69	1·69	1·59
Interstitial	0·42	0·31	0·29
Terminal	1·27	1·38	1·30
2 *Nos. of bivalents with*			
1-chiasma	31	28	32
per cent	39·7	35·9	41·0
2-chiasmata	40	46	46
per cent	51·3	59·0	59·0
3-chiasmata	7	4	..
per cent	9·0	5·2	..
3 *Terminilization coefficient*			
1-chiasma	0·613	0·714	0·656
2-chiasmata	0·863	0·870	0·869
3-chiasmata	0·524	0·667	..

Appendix—*contd.*

TABLE III

Summary of observations of chiasma behaviour
G. arboreum—K1 × G. Stocksii—F_1

	Diplotene	Diakinesis	Metaphase
1 *Nos. of chiasmata*			
Total	52	51	50
Interstitial	18	16	17
Terminal	34	35	33
Terminalization coefficient	0·654	0·686	0·660
1a *Nos. of chiasmata per bivalent*			
Total	1·27	1·19	1·14
Interstitial	0·44	0·37	0·39
Terminal	0·83	0·81	0·75
2 *No. of bivalents with*			
1-chiasma	30	35	38
per cent	73·2	81·4	86·4
2-chiasmata	11	8	6
per cent	26·8	18·6	13·6
3-chiasmata	..	..	..
per cent	..	..	..
3 *Terminalization coefficient with*			
1-chiasma	0·633	0·686	0·532
2-chiasmata	0·682	0·688	1·000
3-chiasmata	..	..	..

MORPHOLOGY OF THE SOMATIC CHROMOSOMES OF THREE ASIATIC COTTONS

BY

P. ABRAHAM, B.A., M.Sc.

Agricultural Research Institute, Coimbatore

(Received for publication on 21 June 1939)

(With three text-figures)

THE morphology of the somatic chromosomes of the three Asiatic cottons, *G. Stocksii* Mast., *G. arboreum* L. var. *neglectum* forma *indica* H. & G. (strain K1) and *G. herbaceum* L. var. *frutescens* Delile (strain 2919) was studied in detail. Root-tips of germinating seeds were fixed in a number of fixatives of which Navashin's fluid was found most satisfactory. The slides were stained in Newton's Gentian violet and Haidenhain's haematoxylin. Both stains gave good results with the above fixing fluid. The lengths of the chromosomes in five metaphase plates have been measured in each species, from root-tips which were fixed the same day and have been given the same treatment. Care was taken to see that the metaphase plates selected for measurement were from approximately analogous portions of the roots and that in all these plates the chromosomes were well spread out with as few bends and curves in the individual chromosomes as possible. The lengths of chromosomes were measured with the aid of an eye-piece micrometer which was adjusted to small lengths so as to enable the bends in the chromosomes to be followed easily. The lengths were then converted into microns. Correction for for-shortening was not done because, as mentioned above, care was taken to see that the metaphase plates selected did not manifest much for-shortening of chromosomes. Table I gives the chromosome size frequencies in a single metaphase plate of each of the three species. For the sake of convenience chromosomes showing approximately the same length in each species have been grouped together in this table.

TABLE I

Chromosomes size frequencies of the three species

Species	Length variations in microns						Total No. of chromosomes
	2·2	2·5	2·8	3·0	3·3	3·6	
G. Stocksii	6	10	6	4	..	..	26
G. arboreum, K1 . . .	6	10	8	2	..	..	26
G. herbaceum, 2919 . . .	..	2	8	6	8	2	26

The differences between the chromosome lengths of the three species have been statistically analysed and the results are given in Table II.

TABLE II

Analysis of variance of the chromosome lengths of the three species

Name of the species	No. of plates examined	Average length per plate	Error per cent	Whether z test was satisfied	Critical difference ($P = 0 \cdot 05$)
G. herbaceum . . .	5	78·3	..	..	..
G. Stocksii . . .	5	68·4	0·76	Yes	1·77
G. arboreum . . .	5	68·0	..	..	..

Conclusion :—*G. herbaceum* > *G. stocksii* = *G. arboreum*

The following conclusions regarding chromosome morphology have been recorded :

CHROMOSOME SIZE

(*a*) The three species studied showed a gradation in the lengths of the chromosomes (figs. 1*a*-3*b*) from the shortest to the longest as was also observed by Skovsted [1934] in *G. arboreum* L. (1·9μ—3·2μ) and Arutjunova [1936] in *G. herbaceum* L. and *G. hirsutum* L. Baranov [1930] also observed differences in size of the respective arms of the chromosomes and of the satellites.

(*b*) The two species *G. arboreum* L. and *G. Stocksii* Mast. have been found to have the same range in the lengths of their chromosomes, which is about 2·2 microns to 3 microns whereas in *G. herbaceum* L., the range is from 2·5 to 3·6 microns, thus revealing a distinct increase in the lengths of all the chromosomes of *G. herbaceum* L. (Table I). The variations in the total length of chromosomes between the three species may be noted from Table II.

(*c*) There is distinct variation in the thickness of the chromosomes among the three species, although under identical fixation and treatment, the chromosomes of each species have been found to show uniform thickness (*Figs.* 1*a*—3*b*). The chromosomes of *G. Stocksii* Mast. are the thinnest, while those of *G. herbaceum* L. are the thickest, *G. arboreum* L. occupying an intermediate position. The differences in thickness indicate differences in volume. These variations in size from species to species may be considered to be genetic characters of the species.

1a

Somatic metaphase plate of *G. stocksii* Mast. (×5000)

1b

Somatic chromosomes of *G. stocksii* Mast. arranged in a line (× 5000)

2a

Somatic metaphase plate of *G. arboreum* L. var. *neglectum*, forma *indica* (×5000)

2b

Somatic chromosomes of *G. arboreum* L. var. *neglectum*, forma *indica*, arranged in a line (×5000)

3a

Somatic metaphase plate of *G. herbaceum* L. var. *frutescens* (×5000)

3b

Somatic chromosomes of *G. herbaceum* L. var. *frutescens* arranged in a line (×5000)

Chromosome morphology

1. In all of the three species examined, two pairs of chromosomes were found to have satellites as was observed by Skovsted [1933, 1935] in these three species and Arutjunova [1936] in *G. herbaceum* L.

2. *Attachment constrictions*—

(*a*) The two pairs of chromosomes with satellites in all the three species appear to be morphologically distinct in that one pair has median attachment constriction whereas the other pair has sub-median attachment constriction at the satellite end.

(*b*) Of the rest of the chromosomes in each of the three species, two pairs have their attachment constrictions situated nearly a third of the length from one end. In *G. Stocksii* Mast. and *G. abroreum* L., these two pairs are among the medium-sized ones whereas in *G. herbaceum* L. one of these two pairs is found to be one of the longest (Figs. 1*a*—3*b*).

(*c*) All the other chromosomes have more or less median attachment constrictions.

According to Skovsted [1934], half of the chromosomes of the American cottons ($2n=52$) are small and the other half longer, the latter being comparable in size to the chromosomes of Asiatic cottons ($2n=26$), and the former to those of American wild species ($2n=26$). This led him to the conclusion that the American cottons ($2n=52$) originated from a cross between an Asiatic cotton and an American wild cotton ($2n=26$). He further states [Skovsted, 1935] that no difference in size and other features could be observed between the somatic chromosomes of the Asiatic cottons, *G. Stocksii* Mast., *G. abrorcum* L. and *G. herbaceum* L. In the present investigation I have observed distinct differences in the size and other morphological features. These studies indicate the need for a re-examination of the problem relating to chromosome size and morphology in the different species of cotton and their hybrids.

Acknowledgements

This investigation was part of the work done by me as a research scholar of the Indian Central Cotton Committee under the guidance of Dr E. K. Janaki Amm M.A., D.Sc., Genetticist, Imperial Sugarcane Breeding Station, Coimbatore.

References

Arutjunova, (1936). *C. R. Acad. Sci.* **3**, 37

Baranov, P. (1930). *Bull. Sci. Res. Cott. Inst. Tashkent* **5**, 7 (through *Plant Breed. Abstracts* **2**, 197)

Skovsted, A. (1933). *Ann. Bot.* **47**, 227

——————— (1934). *J. Gen.* **28**, 407

——————— (1935). *J. Gen.* **31**, 263

ON THE NATURE OF THE REACTIONS RESPONSIBLE FOR SOIL ACIDITY

VI. THE VARIABILITY OF THE TOTAL NEUTRALIZABLE ACID OF COLLOIDAL SOLUTIONS OF HYDROGEN CLAYS*

BY

R. P. MITRA, D.Sc.**

S. K. MUKHERJEE, M.Sc.

AND

S. N. BAGCHI, M.Sc.

Physical Chemistry Laboratory, University College of Science and Technology, Calcutta

(Received for publication on 12 September 1939)

(With seven text-figures)

IN part V of this series [Mitra, 1936] experimental results have been given showing the indefinite character of the total neutralizable acid of a hydrogen clay sol calculated from its titration curves. Using different bases, the titration curves gave different values of the total acid measured at a fixed *p*H. In this paper, the variations of the total acid have been studied in greater detail. The total acid has been estimated on titration in presence and absence of neutral salts. Diffierent concentrations of salts have been used and the titrations carried out with different bases. The total acids of the corresponding ultrafiltrates and leachates have also been measured.

Such investigations have a twofold interest. They are likely, first, to elucidate the electrochemical behaviour of hydrogen clay sols as colloidal acid systems and secondly, to bring out the factors affecting the total amount of acid which enters into the reaction between a soil and an added base, that is, the factors which affect the base binding capacity and the lime requirement of soil. These quantities are rather illdefined [Hissink, 1935], concordant results being seldom obtained by alternative routine methods [Crowther and Martin, 1925]. A knowledge of the factors responsible for the variations is thus necessary. One of the objects of this investigation has been the elucidation of these factors.

Experimental

The method of preparing colloidal solutions of hydrogen clays, the technique of potentiometric and conductometric titrations and the various apparatus used in this work have been described in the previous paper of this series

*The results given in this paper have been taken from the published annual reports for 1935-36 and 1936-37 on the working of a 'Scheme of Research into the Properties of Colloid Soil Constituents' financed by the Imperial Council of Agricultural Research, India and directed by Professor J. N. Mukherjee. The authors' thanks are due to the University of Calcutta for permission to work in the Physical Chemistry Laboratories of the University and for other facilities.

**Senior Assistant Soil Chemist under the above scheme.

[Mitra, 1936]. The soils* from which the hydrogen clays used in this work were prepared are listed below together with the available information regarding them.

1. Suri (Bengal) Farm Soil. Agricultural Chemist's experimental plot. Block A 1—16, plot Nos. 3, 5, 16. No manure. Collected from a depth of 6-in.—12-in.
2. Burdwan (Bengal) Farm Soil. Block B, plot No. 40. Standing crop—Kalai ; surface soil collected from a depth of 0-in.—6-in.
3. Soil from Government Seed Farm, Kalyanpore (U. P.) ; a brown loam ; surface soil included in the ' Doab '.
4. Black Cotton Soil from Satara Dt. (Bombay Province) ; surface soil, calcium saturated and neutral.
5. Black Soil from Bilaspur near Raipur (Central Provinces) ; surface soil, neutral.
6. Red laterite soil from Dacca (Bengal) Farm collected from a depth of 0-in.—6-in.

Aqueous suspensions of hydrogen clays prepared from the clay fractions of the first three soils were centrifuged to obtain stable sols, E, F and H respectively. Sols I, K and L were prepared from hydrogen clays obtained, respectively, from the entire clay fractions of the remaining three soils.

Results

A. Total acidities of colloidal solutions of hydrogen clays obtained on titration with different strong bases

Figs. 1, 2 and 3 show the titration curves of sols E, H and L obtained on titration with different bases.

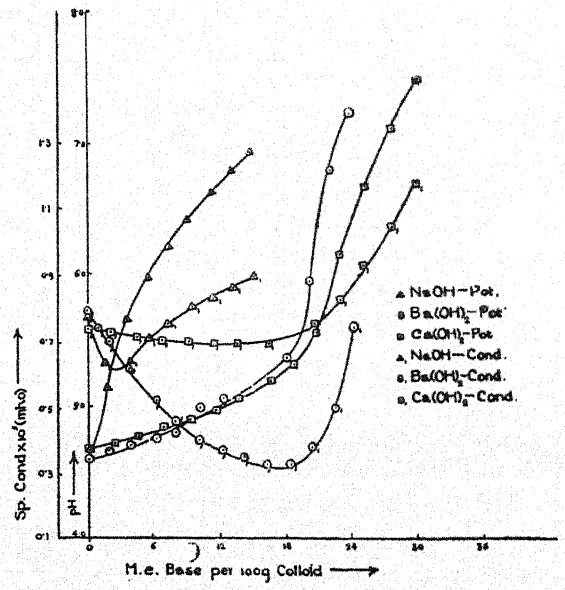


Fig. 1. Sol E

*Soils Nos. 1, 2 and 6 were obtained through the courtesy of the Agricultural Chemist to the Government of Bengal. Soils Nos. 3, 4 and 5 were kindly supplied by the Superintendent, Government Seed Farm, Cawnpore and the Agricultural Chemists to the Governments of Bombay and C. P. respectively.

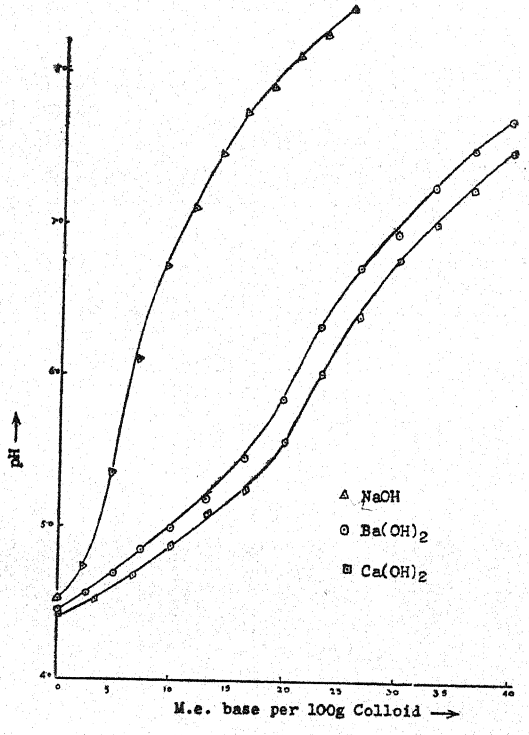


FIG. 2. Sol H

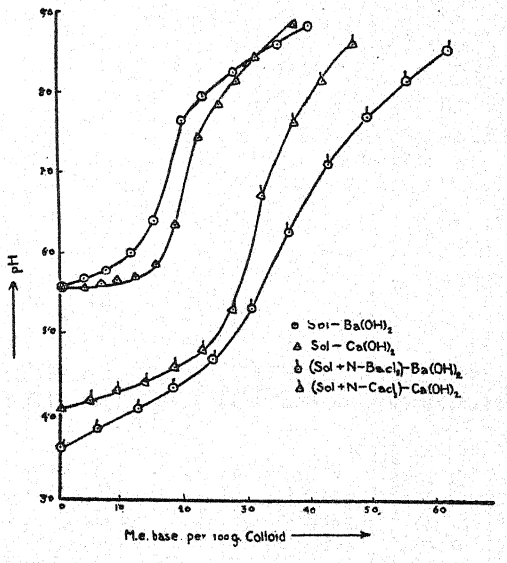


FIG. 3. Sol L

In agreement with previous observations [Mitra, 1936] the titration curves* show definite inflection points and minima. The total acids of the sols calculated from the titration curves at the first ** inflection point and the minimum as also at *p*H 7·0 are given below.

TABLE I

Total acid in m.e. base per 100 gm. colloid (oven-dried)

Sol	Base used for titration	At first inflection point of titration curve	At *p*H 7·0	At minimum of conductometric curve
E	$Ba(OH)_2$	20·6	25·0	19·6
	$Ca(OH)_2$	21·5	26·2	18·0
	NaOH	2·2	15·4	2·5
H	$Ba(OH)_2$	21·5	32·0	n.d.*
	$Ca(OH)_2$	21·5	32·8	n.d.
	NaOH	..	10·7	n. d.
L	$Ba(OH)_2$	17·5	17·0	n. d.
	$Ca(OH)_2$	19·0	19·5	n. d.

* Not determined.

The total acidity of soils E and H at the inflection point, or, the minimum of the conductometric titration curve is less than that at *p*H 7·0. This is to be expected as the inflection points and the minima occur in the acid region.

The total acidities at the inflection point and at *p*H 7·0 which react with different bases are in the order $Ca(OH)_2 > Ba(OH)_2 > NaOH$. Calcium hydroxide appears to have a somewhat greater effect than baryta. The relative effects of these two bases have been more fully dealt with later.

B. EFFECT OF ADDITION OF NEUTRAL SALTS ON THE TOTAL ACIDITY OF HYDROGEN CLAY SOLS

The nature of the titration curve of a hydrogen clay sol with a given base as also the total acidity calculated from the curve have been observed in this work to be modified to a marked extent when the titration is carried out in the presence of a neutral salt. This ' neutral salt effect ' has been studied in some detail. For this purpose, the total acidities of (*i*) the sols, (*ii*) the sol + salt mixtures, (*iii*) the clear supernatant liquids above the coagula of these mixtures and (*iv*) the neutral salt extracts obtained on repeatedly leaching the sols with solutions of the salts have been estimated. Different bases and different neutral salts have been used.

*A detailed discussion of the features of the curves has not been entered into in this paper. This will be done in the concluding paper of this series to be shortly communicated for publication in this journal.

**The titration curves do not show a second inflection up to the *p*H to which the titration had been extended. It might be observed at higher alkaline regions where, however, a ' break-down ' of the exchange complex might occur. Evidence of a complete ' break-down ' of the H-clay from a lateritic soil has been obtained at *p*H 13·5 though no 2nd inflection was observed on titration to this *p*H. Further work on this point is in progress.

(a) Total acids in presence and absence of salts having the same cations as the bases

The following results were obtained with sols E, F, H and L.

TABLE II

Sol	Base used for titration	Ta*	Ta'*	Salt added and conc. of salt	Ts*	Ts'*	Ts/Ta	Ts'/Ta'	**pH(a)	**pH (s)
E	$Ba(OH)_2$.	20·6	25·0	0·1*N* $BaCl_2$	28·0	>42·4	1·31	>1·67	6·0	4·3
	$Ca(OH)_2$.	21·5	26·2	0·1*N* $CaCl_2$.	21·2	40·6	0·97	1·57	5·8	4
	NaOH .	2·2	15·4	0·1*N* NaCl .	16·1	26·4	7·30	1·71	5·4	5·3
F	$Ba(OH)_2$.	31·0	39·4	0·1*N* $BaCl_2$	38·4	64·1	1·24	1·63	6·2	5·2
	NaOH .	9·8	32·0	0·1*N* NaCl .	27·0	56·0	2·70	1·75	5·0	4·8
H	$Ba(OH)_2$.	21·5	32·0	0·83*N* $BaCl_2$	30·5	50·0	1·42	1·56	5·8	4·8
	$Ca(OH)_2$.	21·5	32·8	0·83*N* $CaCl_2$	29·3	47·0	1·36	1·43	6·6	5·0
	NaOH .	...	10·7	0·83*N* NaCl.	22·5	40·0	...	3·8	...	4·8
L	$Ba(OH)_2$.	17·50	17·0	1·0*N* $BaCl_2$	32·0	40·5	1·82	2·31	7·1	5·4
	$Ca(OH)_2$.	19·0	19·5	1·0*N* $CaCl_2$.	30·0	32·5	1·58	1·66	6·6	6·1

*Ta and Ta′ denote the total acidities in m. e. base per 100 gm. of colloid in absence of salt calculated respectively from the first inflection point of the potentiometric titration curve and from the amount of the base which had to be added to make the *p*H of the sol 7·0. Ts and Ts′ denote the corresponding total acidities in presence of salt.

***p*H(s) and *p*H(*a*) denote the *p*H at the first inflection point in the titration curve obtained on titration in presence and absence of salt respectively.

Figs. 3, 4, 5 and 6 show the titration curves from which the total acidities given in table II have been calculated.

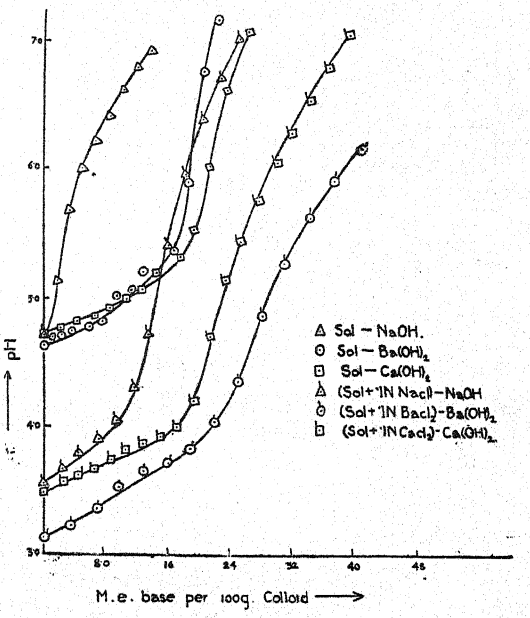


FIG. 4. Sol E

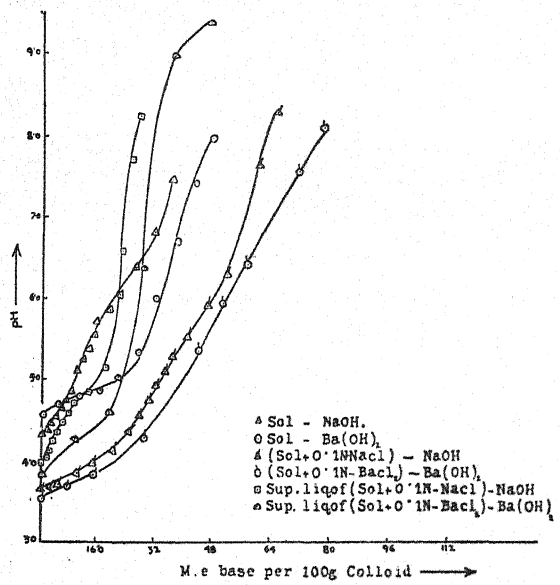


FIG. 5. Sol F

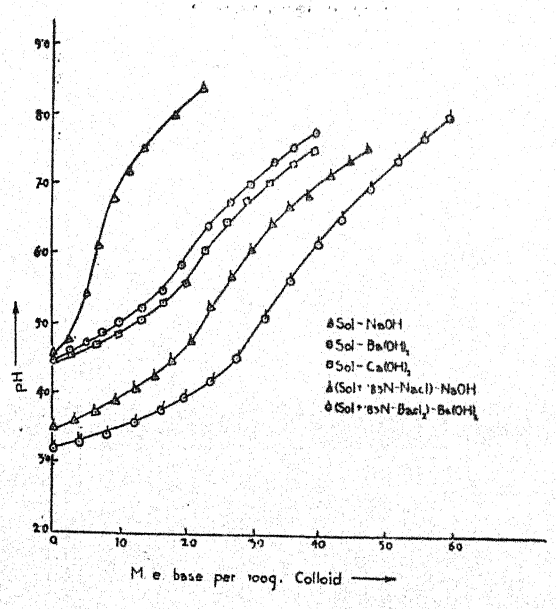


FIG. 6. Sol H

The results show that a considerably larger value of the total acid calculated at the inflection point of the titration curve is obtained when the sol is titrated in the presence of a salt than when titrated alone. In making this comparison, the *p*H at which the total acids are measured is an important factor for, as the titration curves show, increasing amounts of the acid react with the base as the *p*H rises. The inflection point in the titration curve of a sol +salt mixture occurs at a lower *p*H than the inflection point in the titration curve of the sol itself (Table II). It is significant that even then a larger value of the total acid (calculated at the inflection point) is obtained on titration in the presence of the salt than in its absence. The cations of the salt present in large numbers thus have an unmistakable effect on the total amount of the acid reacting with the base. This *cation effect* is as important a factor in determining the total acid as the *p*H at which it is measured. It is strikingly brought out on comparing the total acids of the sol (Ta′) and the sal + salt mixture (Ts′) at the same *p*H, e.g. *p*H 7·0. Ts′ is always greater than Ta′.

Table II shows a slightly lower value of the total acid (at the inflection point) of sol E when it is titrated with Ca $(OH)_2$ in presence of 0·1 *N* $CaCl_2$ than when titrated alone. The difference is only $\pm$1·5 per cent and lies within the limits of experimental error. The failure to obtain a larger total acid in the presence of the salt arises mainly from the fact that the inflection point in the titration curve occurs at a much lower *p*H when the sol is titrated with the salt than when the sol alone is used. Measured at *p*H 7·0, the sol + $CaCl_2$ mixture shows a much larger total acid than the sol itself indicating a distinct cation effect.

Titration with caustic soda in the presence of NaCl. shows the highest relative increase (highest value for Ts/Ta) in the total acid calculated at the first inflection point. This signifies that at the inflexion point caustic soda neutralizes only a small fraction of the H^+ ions associated with the colloidal particles. It neutralizes them after they have been exchanged for the cations of the salt.

A reference to Table II will further show that the total acid (both at the first inflection point and at *p*H 7·0) reacting with different bases in the presence of the corresponding salts at the same concentration follows the order: $Ba(OH)_2$> $Ca(OH)_2$> NaOH. The order of total acidities, however, changes to $Ca(OH)_2$> $Ba(OH)_2$> NaOH when the sols alone are titrated.

The following results illustrate the dependence of the total acid on the concentration of the added salt.

TABLE III

Sol	Base used for titration	Salt added	Conc. of salt	Ta*	Ta′*	Ts*	Ts′*	Ts/Ta	Ts′/Ta′
E	NaOH	NaCl	0·01*N*	2·2	15·4	16·4	19·5	7·45	1·27
	NaOH	NaCl	0·1*N*	2·2	15·4	16·1	26·4	7·30	1·71
	$Ba(OH)_2$	$BaCl_2$	0·01*N*	20·6	25·0	20·8	25·5	1·00	1·02
	$Ba(OH)_2$	$BaCl_2$	0·1*N*	20·6	25·0	28·0	>42·4	1·31	1·67
H	$Ba(OH)_2$	$BaCl_2$	0·05*N*	21·5	32·0	25·0	38·0	1·16	1·19
	$Ba(OH)_2$	$BaCl_2$	0·25*N*	21·5	32·0	27·0	44·0	1·26	1·37
	$Ba(OH)_2$	$BaCl_2$	0·83*N*	21·5	32·0	30·5	50·0	1·42	1·56

*Ta. Ta′, Ts and Ts′ have the same significance as indicated before.

Fig. 7 shows the titration curves of sol H and sol H + $BaCl_2$ mixtures from which their total acids given in table III have been calculated.

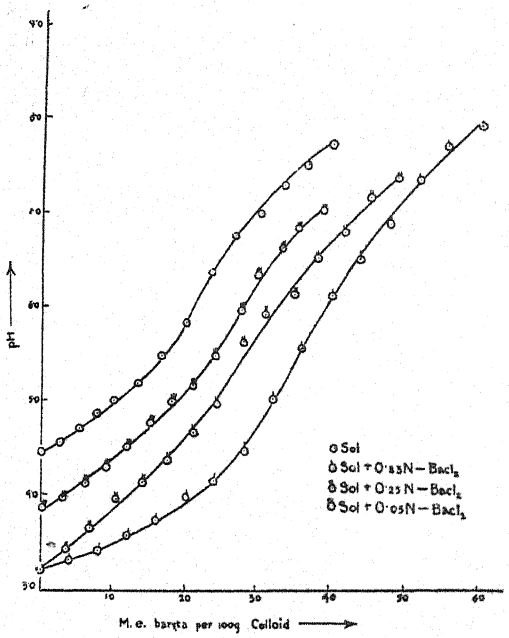


FIG. 7, Sol H

Beginning with the titration curve of the sol at the extreme left a lateral displacement of the curves of the sol + salt mixtures towards the right is observed as the concentration of the salt in the mixture increases indicating a gradual increase in the total acidity with the concentration of the salt in the mixture.

(*b*) *The total acidities of* (*i*) *the sol,* (*ii*) *the sol + salt mixture and* (*iii*) *the clear supernatant liquid above the coagulum of the sol + salt mixture*

In Fig. 5 are given the titration curves of (*i*) sol F, (*ii*) mixtures of sol F and salts (0·1N) and (*iii*) the clear supernatant liquids above the coagula of these mixtures.

The inflection points in the titration curves of (*iii*) are sharper than those of (*i*) and (*ii*) which signifies that a strong acid is being neutralized in (*iii*). The titration curves of (*iii*), however, show a slight initial rise followed by a small region of stronger buffering before the sharp inflection is observed. The initial rise would not be expected if only hydrochloric acid formed by the interaction of the hydrogen clay and the neutral salt were being titrated in (*iii*). It would be expected if (*iii*) also contained some '*displaced*' *aluminium ions*. In the next paper of this series it has been shown that using a sufficiently

low concentration of the salt, preferably that of an alkali metal cation, the titration curve of (*iii*) has a truly strong acid character, the above initial rise not being in evidence. Also, actual analysis has shown that under these conditions (*iii*) contains practically no Al^{+++} ions.*

The total acidities calculated from the titration curves given in fig. 5 are shown in the following table.

TABLE IV

System	Total acid in m. e. Ba $(OH)_2$ per 100 gm. of colloid	
	At first inflection point	At *p*H 7·0
(i) Sol F	31·0	39·4
(ii) Sol F + $BaCl_2$ mixture	38·4	64·1
(iii) Supernatant liquid of (ii)	..	30·9

The total acidities are in the order (*ii*) > (*i*) > (*iii*). The difference between the total acids of (*ii*) and (*iii*) signifies that at the concentration used, the salt does not displace all the hydrogen ions associated with the colloidal particles into the intermicellary liquid of the sol and that a part of the hydrogen ions brought into a reactive condition by the neutral salt still remains associated with the colloidal particles and these are capable of reacting with the base.

(*c*) *The total acidity of* (*i*) *the sol,* (*ii*) *the sol + salt mixture and* (*iii*) *the neutral salt extract obtained by repeatedly leaching the sol with the salt solution.*

Leaching with neutral salts is often resorted to in the estimation of the lime requirement of soil by the titration of the salt extract [Hopkins, 1903; Daikuhara, 1914; Gedroiz, 1924]. It has been shown above that the addition of the salt to the sol does not displace into the intermicellary liquid all the H^+ ions which are brought into a reactive, that is, neutralizable condition and which can, therefore, be estimated only by titrating the sol + salt mixture *in situ*. It was thus of interest to compare the amount of acid displaced by repeated leaching of the sol with the salt solution. This has been done with sol H. The solution with which the sol was leached had the same concentration (0·83*N*) as obtained in the sol + salt mixture. The following results were obtained.

*The subject is being systematically studied by Mr. B. Chatterjee in this laboratory.

TABLE V

System	Total acid in m. e. base per 100 gm. colloid using $Ba(OH)_2$ and $BaCl_2$		NaOH and NaCl	
	At first inflection pt.	At *p*H 7·0	At first inflection pt.	At *p*H 7·0
Sol	21·5	32·0	..	10·7
Sol + Salt	30·5	50·0	22·5	40·0
1st 100 c.c. of leachate	..	17·0	..	15·0
2nd 100 c. c. of leachate	..	3·0	..	2·0
3rd 100 c.c. of leachate	..	1·2	..	1·8

In agreement with the results given in Table II the total acidity of the sol + salt mixture is greater than that of the sol alone. The sum of the total acidities of the three leachates, however, is less than the total acidity of the sol + salt mixture. Of the three leachates, the total acidity of the first is the highest, then there is a sudden drop, the total acid of the third leachate being almost negligible. Thus treatment of the hydrogen clay sol with the salt solution, to the extent that practically no further acid comes out in the leachate, does not displace from the colloidal particles of the sol all the acid which can react with the base in presence of the salt. The salt and the base when they can react together liberate the greatest amount of acid under the conditions compared. *Of this amount a part is liberated into the intermicellary liquid and another part remains associated with the colloidal particles.*

Table V shows that when leached with barium chloride a greater amount of colloid-free acid is obtained in the extract than with sodium chloride using equal concentrations. This is in agreement with the greater total acidity (previously observed) of the sol + salt mixture obtained on titration with $Ba(OH)_2$ than NaOH in presence of $BaCl_2$ and NaCl respectively.

C. THE RELATIVE EFFECTS OF Ba^{++} AND Ca^{++} IONS IN THE INTERACTIONS OF THEIR SALTS AND BASES WITH HYDROGEN CLAYS

The results given in the preceding sections show that in the interactions of hydrogen clays with bases both in the presence and absence of neutral salts a definite cation effect exists. In the interactions in presence of salts the relative effects of the cations agree with the lyotrope series and Ba^{++} has an unmistakably greater effect than Ca^{++}. Previous work from this laboratory [Mitra, 1936] shows that the H^+ ion activity of a hydrogen clay sol shows characteristic variations on progressive additions of a neutral salt and the

relative effects of different salts having a common anion also follow the lyotrope series, that is, Ba^{++} has a greater effect than Ca^{++}. The following results further illustrate this point.

TABLE VI

Sol	Conc. of the added salt $\times 10^3 N$	Lowering of pH	
		With $BaCl_2$	With $CaCl_2$
H	1·5	0·48	0·45
	3·0	0·51	0·49
	40·5	0·87	·77
I	1·0	0·67	0·65
	5·0	·82	·73
	45·0	1·09	1·03
I′	1·5	0·65	0·60
	6·8	·84	·81
	50·5	1·14	1·02
K	1·20	0·65	0·61
	9·00	·95	·90
	42·00	1·19	1·12
K′	1·20	0·68	0·61
	9·00	·88	·81
	42·00	1·12	1·00

Hydrogen clays I′ and K′ were obtained from the same soils as hydrogen clays I and K with the difference that the colloidal materials of these soils were treated according to the method of Drosdoff and Truog [1935] to remove their free silica, alumina and ferric oxide before converting them into hydrogen clays I′ and K′.

Table VI shows that barium chloride lowers the pH of the sol to a greater extent than calcium chloride at the same concentration. The difference in the relative effects of the two ions persists even after removal of free silica and sesquioxides from the hydrogen clay as the results obtained with sols I′ and K′ show.

Reference has already been made to the fact that calcium hydroxide reacts more strongly than baryta with a hydrogen clay sol to which no salt has been added indicating a greater relative effect of Ca^{++} than Ba^{++} ions under these conditions. This is further illustrated by the following results.

TABLE VII

Sol	Base used for titration	*p*H at inflection point	Total acid in m. e. base per 100 gm. of colloid		
			At inflection point.	At *p*H 7·0	At *p*H 9·0
H	$Ba(OH)_2$	5·80	21·5	32·0	..
	$Ca(OH)_2$	6·60	21·5	32·8	..
I	$Ba(OH)_2$	7·00	82·0	82·0	101·5
	$Ca(OH)_2$	6·95	96·0	97·0	122·0
I′	$Ba(OH)_2$	7·60	91·0	85·0	106·0
	$Ca(OH)_2$	6·50	86·0	91·0	114·0
K	$Ba(OH)_2$	5·80	55·0	61·0	81·0
	$Ca(OH)_2$	5·20	58·0	67·0	86·0
K′	$Ba(OH)_2$	5·75	56·0	62·0	75·5
	$Ca(OH)_2$	5·78	63·0	68·5	81·5

Calcium hydroxide reacts with the sol more strongly than baryta even beyond the neutral point (at *p*H 9·0). This difference in the relative effects of Ba^{++} and Ca^{++} ions in the interactions of their salts and bases with hydrogen clays illustrates *two different types of cation effect* discussed in the next section.

D. THE ROLE OF THE ELECTRICAL DOUBLE LAYER AND OF THE SECONDARY ADSORPTION OF CATIONS IN DETERMINING THE TOTAL NEUTRALIZABLE ACID OF A HYDROGEN CLAY SOL

The results previously given bring out the variable character of the total neutralizable acid of a hydrogen clay sol. The total acid is a function (1) of the *p*H at which it is measured and (2) of ' cation effects'. The cation effect finds expression in the different total acids, measured at the same *p*H, obtained on titration with different bases as also in the considerably larger total acid obtained on titrating the sol in the presence of a neutral salt than on titrating it alone. Such variations in the total acid are not possible for any truly dissolved acid.

The theory of the electrical double layer postulating the existence of primarily adsorbed ions associated with the colloidal particles of the sol and of a secondary adsorption of cations by them [Mukherjee, 1921, 1922] affords a satisfactory basis for an interpretation of the cation effects and the variations

of the total acid.* According to the theory, H^+ ions corresponding to the primarily adsorbed anions which are assumed to be 'built in' on the solid side of the solid-liquid interface may exist in two states, viz. (1) in a secondarily adsorbed condition either by simple electrostatic forces, or, by specific forces of the chemical or forces of the Van der Waals' type and (2) in a free, or, 'mobile' state which determines the free charge of the surface. The distribution between the two states depends on the nature of the colloid and that of the intermicellary liquid. The H^+ ions of both categories may be displaced by the cations of an added salt or a base, these cations being themselves adsorbed in the process; the displacement of H^+ ions of the second category is obviously the easier. The adsorption, i.e. fixation of the cations leads to the formation of 'ion pairs' on the surface and is brought about by electrostatic forces of attraction and/or by specific forces, e.g. of a chemical or Van der Waal's type. In the former case, only the electrical properties of the cations, e.g. their valency, mobility and state of hydration (which determines the distance between the centres of the ions constituting the ion pairs formed by adsorption) are the factors which determine the intensity of their adsorption and hence the amount of H^+ ions exchanged. In the interaction with a base, these exchanged H^+ions are neutralized by the OH—ions of the latter. The possibility of a direct neutralization of some H^+ ions by the OH— ions is not excluded. The greater total acidity measured at a given *p*H obtained on titration with baryta or calcium hydroxide compared to caustic soda is, on this view, due to a greater electrical adsorption of Ba^{++} and Ca^{++} ions compared to that of Na^+ions. A greater total acid obtained on titration with a given base in the presence of a salt than in its absence similarly arises from a stronger adsorption of the cations because of their being present in larger numbers.

The increase in total acid observed on titration in the presence of a salt may be due to aluminium ions which, as our later work shows, are always present in the supernatant liquid above the coagulum of the sol + salt mixture whenever such an increase in the total acid is observed. The aluminium ions may have been directly exchanged for the cations of the salt, or, they may have been dissolved out from the hydrogen clay by the free acid liberated by its interaction with the salt. The mechanism of the liberation of such aluminium ions is of no direct significance so long as discussions of the cation effects are restricted, as has been done here, to their role in determining the total neutralizable acids of the sol + salt mixtures and their clear supernatant liquids.

The difference in the relative effects of Ba^{++} and Ca^{++} ions in the interactions of their salts and bases with hydrogen clays may be explained as follows. The greater relative effect of Ba^{++} compared to Ca^{++} in the interactions with the salts arises from a stronger electrical adsorption of Ba^{++} than Ca^{++}, the relative electrical adsorbability of the ions being determined by their electrical properties, viz. their valency, mobility and state of hydration. The cation effect is thus electrical in origin and follows the

*The picture here suggested is of a general nature. It takes no account of (*i*) the amphoteric character of the hydrogen clays (*ii*) the role of Al^{+++} and other ions on the surface in addition to H^+ ions and (*iii*) the detailed structure of the hydrogen clays. Work covering these aspects is under way.

lyotrope series. It may thus be called a *regular cation effect*. The greater relative effect of Ca^{++} than Ba^{++} ions in the interactions with the bases is an '*irregular or specific cation effect* in the sense that it does not follow the lyotrope series. This second type of cation effect' does not result from simple electrical adsorption (by electrostatic forces) of the cations together with their hydration envelopes. Here, the cations are adsorbed by specific forces other than simple electrostatic forces in a dehydrated state. The two types of cation effect will be further discussed in the concluding paper of this series.

Summary

The total neutralizable acid of a hydrogen clay sol calculated at the first inflection point and the minimum of its potentiometric and conductometric titration curves with bases as also at *p*H 7·0 is a variable quantity. The variations arise from cation effects whose nature has been discussed in the light of the theory of the electrical double layer and of adsorption of ions.

On titration with different bases in absence of salts, the total acid decreases in the order $Ca(OH)_2 > Ba(OH)_2 > NaOH$. The greater relative effect of $Ca(OH)_2$ compared to $Ba(OH)_2$ illustrates an '*irregular, or, specific cation effect*'

With a given base, titration in the presence of a salt yields a much larger total acid than titration of the sol alone. The cations present in large numbers have an effect.

On titration in presence of the same concentration of the corresponding chloride, the total acid decreases in the order $Ba(OH)_2 > Ca(OH)_2 > NaOH$. Here, a '*regular cation effect*' is observed which is in agreement with the (lyotrope) series.

The total acid of the sol+salt mixture obtained on titrating it *in situ* is greater than that of (*i*) the clear supernatant liquid above the coagulum of the mixture as also (*ii*) the salt extract obtained on repeatedly leaching the hydrogen clay with the solution of the salt. A considerable amount of titratable acid thus remains associated with the coagulum of the mixture which cannot be displaced in the intermicellary liquid of the sol even on repeatedly leaching it with the solution of the salt.

REFERENCES

Crowther, E. M. and Martin N.S., (1925). *J. Agric. Sci.* **15**, 237
Daikuhara, G. (1914). *Bull. Jap. Imp. Centr. Agric. Exp. Sta.* **2**, 1
Drosdoff, M. and Truog, E. (1935). *Trans. 3rd Internatl. Cong. Soil Sci.* **1**, 92
Gedroiz, K. K. (1924). *J. Exp. Agron.* **22**, 3
Hissink, D. J. (1935). *Trans. 3rd Internatl. Cong. Soil Sci.* **2**, 68
Hopkins, C. G. (1903). *U. S. Dept. Agric. Bur. Chem. Bull. No.* **73**
Mitra, R. P. (1936). *Ind. J. Agric. Sci.* **6**, 555
Mukherjee, J. N. (1921). *Trans. Far. Soc.* **16**, 103
——————— (1922). *Phil. Mag.* **44**, 321

VII. THE ELECTROCHEMICAL PROPERTIES OF COLLOIDAL SOLUTIONS OF HYDROGEN CLAYS*

BY

R. P. MITRA, D.Sc.**

Physical Chemistry Laboratory, University College of Science and Technology, Calcutta

(Received for publication on 12 September 1939)

(With ten text-figures)

IN Part V of this series [Mitra, 1936] mention has been made of several points of difference which exist between the titration curves of colloidal solutions of hydrogen clays and those of acids in true solution. In part VI [Mitra, Mukherjee and Bagchi, 1940] it has been shown that the total acidity of a hydrogen clay sol calculated from titration curves obtained on titrating the sol under different conditions, e.g. with different bases or, with a given base but in the presence and absence of a neutral salt, is, also unlike any dissolved acid, a variable quantity. In this paper, the special features of hydrogen clay sols which distinguish them from acids in true solution have been considered in greater detail and an attempt has been made to reconcile them in a general picture which is based on the theory of the electrical double layer and of adsorption of ions.

Experimental

The hydrogen clay sols used were prepared from the following Indian soils† in the manner previously described [Mitra, 1936].

Sol	Soil from which the hydrogen clay was obtained
D	Virgin soil from Dacca Farm (Bengal) collected from a deptl of 0 to 6 in.
E	Suri (Bengal) farm soil. Agricultural Chemist's experimental plot. Block A 1-16, plot Nos. 3, 5, 16. No manure ; soil collected from a depth of 6 to 12 in.
F	Burdwan (Bengal) Farm soil. Block B, plot No. 40. Standing crop—*kalai* ; surface soil collected from a depth of 0 to 6 in.
G	Krishnagar (Bengal) farm soil ; highland soil collected from a depth of 0 to 6 in.
H	Soil from Government Seed Farm, Kalyanpore (U. P.) ; a brown loam included in the *Doab* ; collected from a depth of 0 to 6 in.
I	Black cotton soil from Satara Dt., Bombay Presidency ; surface soil, calcium saturated, neutral.
K	Black soil from Bilaspur near Raipur (C. P.) ; surface soil.

* The results given in this paper have been taken from the published annual reports for 1935-36 and 1936-37 on the working of a scheme of ' Research into the Properties of Colloid Soil Constituents ' financed by the Imperial Council of Agricultural Research, India, and directed by Professor J. N. Mukherjee. The author takes this opportunity to thank the University of Calcutta for permission to work in the Physical Chemistry laboratory of the University and for other facilities.

** Senior Assistant Soil Chemist under the above scheme.

† The first four soils were kindly supplied by the Agricultural Chemist to the Government of Bengal. The Kalyanpur Farm Soil was obtained through the courtesy of the Superintendent, Government Seed Farm, Cawnpore. The two black soils were kindly supplied by the agricultural chemists to the Governments of Bombay and the Central Provinces, respectively.

The experimental arrangements and procedure were as previously described [Mukherjee *et. al.*, 1936 ; Mitra, 1936].

The hydrogen clay sols used covered a range of H ion concentrations from 10^{-5} *N* to 10^{-4} *N* and had specific conductivities of the order of 10^{-5} to 10^{-6} mho. The significance and degree of accuracy of estimations of free and total acids of such systems have been discussed in two previous parts of this series [Mukherjee, *et. al.*, 1936 ; Mitra, 1936]. Since the publication of these papers, it has been possible to further improve upon the reproducibility and accuracy of the *p*H data [Mukherjee, Mitra and Mukherjee, 1937] by more careful attention to preparation and cleansing of the electrodes and the inclusion of glass electrodes* used in conjunction with a valve potentiometer.** The results given in Table I obtained with some hydrochloric acid solutions which had nearly the same *p*H as the sols illustrate the order of accuracy now attained. The first, second and third columns of the table give the *p*H obtained with the hydrogen (*h*), glass (*g*) and quinhydrone (*q*) electrodes respectively. The fourth column gives the *p*H calculated from the observed specific conductivity from the known mobilities of H^+ and Cl^- ions and assuming complete dissociation of the acid. The fifth column gives the value of $\log \frac{1}{[Cl^-]}$ the Cl^- ion concentration having been determined by conductometric titration with silver sulphate solution. The sixth column gives the *p*H corresponding to the total acidity calculated from the potentiometric or conductometric titration curve of the acid assuming complete dissociation. Hydrogen and glass electrodes were used for the potentiometric titrations.

TABLE I

	*p*H (h)	*p*H (g)	*p*H (q)	*p*H (cond.)	Total Cl $\log \frac{1}{[Cl]}$	*p*H (T)
	2·94	2·94	2·96	3·08	2·96	3·00 (glass electrode)
	2·96					3·02 (hydrogen electrode)
Average :	2·96					
	4·34	4·30	4·30	4·42	4·41	4·40 (glass electrode)
	4·36					4·42 (hydrogen electrode)
	4·36					4·42 (conductometric)
	4·32				Average	4·41
Average :	4·35					
	5·12					
	5·10	5·08	5·13	5·23		5·18 (glass electrode)
	5·11					5·14 (conductometric)
Average	5·11				Average	5·16

* Morton type glass electrodes were used.

** A Cambridge *p*H meter reading directly to 2 millivolts.

The average *p*H values obtained with the hydrogen electrode agree with the value obtained with the glass or quinhydrone electrode within 1 per cent. The average of glass, quinhydrone and hydrogen electrode values for the three solutions are respectively 2·95, 4·32 and 5·11. These values agree with the respective total acidity values within 2 per cent.

With the experimental arrangement used, some KCl from the salt bridge has been occasionally found to find passage into the titration vessel thereby increasing the conductivity of the solution. Consequently, for accurate determinations of the absolute values of the conductivities and for studying the fine features of the conductometric titration curves, the conductometric measurements were carried out separately from the potentiometric maesurements thus obviating the use of the KCl-bridge.

Results

I. Hydrogen clay sols are not homogeneous acid systems

In the following table the free and total acids of a number of hydrogen clay sols have been compared with those of their ultrafiltrates. The free acid has been calculated from the observed *p*H and the total acid from the inflexion point of the potentiometric titration curve obtained on titration with barium hydroxide.

Table II

System	*p*H	Free acidity (H ion conc. × 10^5)	Total acidity (N) × 10^5
Sol D . . .	5·40	0·40	5·0
Ultrafiltrate of sol D .	5·95	0·11	Negligible
Sol E . . .	4·66	2·19	24·30
Ultrafiltrate of sol E .	6·10	0·08	Negligible
Sol F . . .	4·41	3·89	38·0
Ultrafiltrate of sol F .	5·90	0·13	Negligible
Sol G . . .	4·57	2·69	40·0
Ultrafiltrate of sol G .	5·85	0·14	*n. d.**
Sol H . . .	4·52	3·02	99·0
Ultrafiltrate of sol H .	6·05	0·09	*n. d.**

* Not determined

The free and total acids of the ultrafiltrate are considerably less than those of the sol itself. A separation of the colloidal particles from the liquid phase by ultrafiltration thus causes a marked lowering of its H^+ ion activity and total acidity. A two phase acid character of the sol, the colloidal particles constituting one phase and the intermicellary liquid the other, is thus brought

out. There are osmotically active H^+ ions associated with the colloidal particles which, rather than any H^+ ions present in a truly dissolved condition in the intermicellary liquid, are responsible for the observed H^+ ion activity and total acidity of the sol. The observations are in agreement with the socalled ' suspension effect ' of Wiegner and Pallmann [1929].

II. Discrepancies between conductivity and activity measurements with colloidal solutions of hydrogen clays

The peculiar phasal condition of the H^+ ions associated with the colloidal particles of a hydrogen clay sol is further illustrated by the following significant discrepancies between the specific conductivities of the sols actually measured and those calculated from their activity data. The results obtained with sols H_1 and J and with sols prepared by diluting them with their respective ultrafiltrates are given in Table III. The ultrafiltrates had *p*H values 6·09 and 6·20. Sol H_1 was obtained from the same soil as sol H. Only, it had a higher colloid content than sol H.

Table III*

Sol	H+ ion conc. in normality $\times 10^5$	Sp. conductivity in mho $\times 10^5$ (Observed)	Sp. conductivity in mho $\times 10^5$ (Calculated)
H_1	8·7	1·02	3·48
$H_{\frac{1}{2}}$	5·01	0·97	2·04
$H_{\frac{1}{4}}$	3·16	0·61	1·26
J	14·45	2·20	5·16
J/4	3·72	0·88	1·37
J/6	2·57	0·66	1·17

The H^+ ion concentrations were calculated from the observed *p*H values of the sols measured with hydrogen and glass electrodes. For the conductivity measurements, a Washburn cell having a cell constant 0·0095 in conjunction with a Vreeland Oscillator as the source of the alternating current was used.

* The results given in this table have been taken from a paper read at a meeting of the Chemistry Section of the Indian Science Congress Association, held in January, 1938. An abstract of the paper has appeared in the Proceedings of the Congress (Proceedings, 1938, Vol. 3, p. 53).

The values of the calculated specific conductivity given in the above table were obtained with the aid of the equation $\mu cal = C_H{}^+ U_H{}^+$ where $U_H{}^+$ is the equivalent conductance of H^+ions and $C_H{}^+$,the H ion concentration** calculated from the *p*H. The conductivity due to the anions, that is, the negatively charged colloidal particles has been neglected. The results given in Table III reveal the interesting fact that the actual specific conductivity is less than even the conductivity due to the H^+ ions calculated from their observed activities. These H^+ ions are not present in the intermicellary liquid of the sol as is shown by the fact that while the sols have H ion activities of the order of $10^{-4}N$ to $10^{-5}N$ those of their ultra-filtrates are of the order of $10^{-7}N$. The results, therefore, show that though these H^+ions register their activity on a reversible electrode, they do not take part in the conduction of electricity in the usual manner. Their average conductivity coefficient is much less than unity [Mukherjee, 1933]. This behaviour of hydrogen clay sols has not been previously observed* and it constitutes a peculiar feature of such systems.

Discrepancies between conductivity and activity measurements in colloidal solutions have been used by Mukherjee [1933] as an argument in favour of the existence of an electrical double layer in such systems. Hartley [1935] has sought to reconcile them in the light of a modified form of Debye and Hückel's theory of electrolytic conduction. McBain and Betz [1935] consider that the discrepancies are such as cannot always be explained by any reasonable modification of the existing theories.

III. Interactions of colloidal solutions of hydrogen clays with neutral salts

When added to acid soils, neutral salts have long been known to liberate acid. Several well-known methods of estimating the lime requirement of soil, e.g. those due to Hopkins [1903], Daikuhara [1914] and Gedroiz [1924] are based on this principle. The nature of the interactions involved which has been the subject of controversies [Russell, 1937] is likely to be elucidated by systematic studies of the effect of neutral salts on hydrogen clays. Such studies have been made, comparatively recently by Wiegner [1931], Jenny [1932, 1936], Marshall and Gupta [1933], Mattson [1932, 1935] and others. The following investigations deal with some special features of the interaction.

1. Interchanges between the diffusible H^+ions associated with the colloidal particles of a hydrogen clay sol and the cations of an added salt

In the following table the differences of the *p*H of hydrogen clay sols H and P and those of their ultrafiltrates have been compared with the corresponding differences observed when the sols contained sodium and potassium chlorides in small concentrations.

** As $C_H{}^+$ is of the order of $10^{-5}N$ to $10^{-4}N$, the concentration and the activity have the same significance.

* Discrepancies between the actual and calculated specific conductivities of hydrogen bentonite systems have been reported by Hauser and Reed (*J. Phys. Chem.* **41**, p. 911, 1937) since the communication to the Indian Science Congress Association of the paper dealing with the results given in this section. Similar discrepancies with hydrogen bentonites have also been observed by us (unpublished work).

TABLE IV

System	*p*H	e. m. f. (in volts) of conc. cell H_2/Sol+salt/sat. KCl/ ultrafiltrate/H_2 of I	
		I	II
		(Obs.)	(Calc.)
Sol H	4·52		
Ultrafiltrate of sol H	6·05		
Sol H+0·0005*N* KCl	4·26		
Ultrafiltrate of above	4·42		
Sol H+0·002*N* KCl	4·10		
Ultrafiltrate of above	4·15		
Sol P*	4·54		
Ultrafiltrate of sol P.	5·85		
Sol P+0·0005*N* NaCl	3·85	0·032	0·030
Ultrafiltrate of above	4·35		
Sol P+0·002*N* NaCl	3·71	0·014	0·014
Ultrafiltrate of above	3·95		
Sol P+0·0005*N* KCl	3·80	0·027	0·029
Ultrafiltrate of above	4·28		
Sol P+0·002*N* KCl	3·70	0·011	0·012
Ultrafiltrate of above	3·90		

The differences between the *p*H values of the sol P+salt mixtures and those of the corresponding ultrafiltrates were checked by e. m. f. measurements with concentration cells of the type H_2/Sol+Salt/Sat. KCl/Ultrafiltrate of I/H_2.

I II

The actual e. m. f.'s are in good agreement with those calculated from the *p*H values of I and II separately determined.

The results given in Table IV show that on the addition of the salt the *p*H of the sol itself changes only to a small extent compared to that of the ultrafiltrate. Apparently, a change has taken place in the sol in the location of the H^+ions and their distribution between the colloidal particles and the intermicellary liquid which constitute two distinct phases. Hydrogen ions which were previously intercepted by the membrane can now pass through it. Originally, these hydrogen ions were associated with the colloidal particles themselves though mostly in an osmotically active, or, diffusible condition.

* This sol was prepared from a Deccan black soil (type 'B') kindly supplied by Dr J. K. Basu of the Sugarcane Research Station, Padegaon, Bombay.

On the addition of the neutral salt they have interchanged their positions with the cations of the salt and have passed into the intermicellary solution. This however, has not greatly affected the observed H^+ ion activity of the sol as the H^+ ions taking part in the interchange were mostly in an osmotically active, i.e. diffusible condition previous to the interchange. The marked increase of the H^+ ion activity of the ultrafiltrate, on the other hand, is readily explained by their displacement into the intermicellary solution. Similar observations with silicic acid sols have previously been made by Mr. B. Chatterjee in this laboratory (cited by Mukherjee, Mitra and Mukherjee [1937]).

2. Interchanges between diffusible as well as non-diffusible H^+ions associated with the colloidal particles of a hydrogen clay sol and the cations of an added salt

The variations of *p*H of hydrogen clay sols H and P recorded in Table IV are small as the salt was added only in small concentrations. Considerably larger variations were observed using larger concentrations of salts as the following results will show :—

TABLE V

Sol	*p*H of sol	CH+ of sol × 10^4	Salt added and conc. of salt	*p*H of sol+salt	CH+of Sol+ salt × 10^4
E			0·10 *N* NaCl	3·61	2·45
	4·66	0·22	0·10 *N* $CaCl_2$	3·52	3·02
			0·10 *N* $BaCl_2$	3·15	7·08
H			0·80 *N* NaCl	3·46	3·46
	4·52	0·32	0·80 *N* $CaCl_2$	3·33	4·67
			0·80 *N* $BaCl_2$	3·23	5·87
I			0·25 *N* $CaCl_2$	3·43	3·72
	4·51	0·31	0·25 *N* $BaCl_2$	3·31	4·90
K			0·25 *N* $CaCl_2$	3·30	5·01
	4·47	0·34	0·25 *N* $BaCl_2$	3·02	9·55

The curves given in Figs. 1 and 2 show the variations in the H^+ion activity of sols E and H on progressive additions of NaCl, $BaCl_2$ and $CaCl_2$.

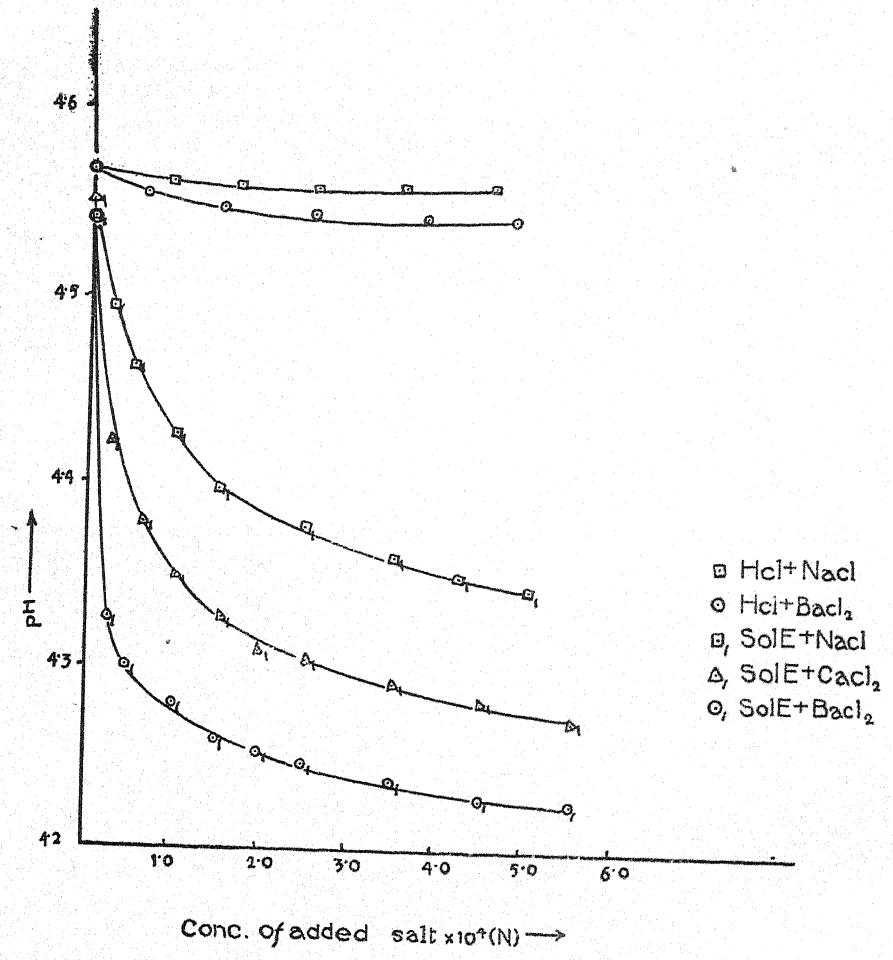


FIG. 1

The curves as also the results recorded in Table V show, in agreement with previous observations [Mitra, 1936], that using chlorides alone, the effect of different cations in increasing the H^+ion activity is in the order $Ba^{++} > Ca^{++} > Na^+$ which follows the usual lyotrope series. The increase of the H^+ ion activity may be due (*i*) to an alteration of the activity coefficient of the free (osmotically active) hydrogen ions associated with the colloidal particles and/or (*ii*) to a change from an osmotically inactive to an active condition of H^+ions following the addition of the salt. Without the salt, these H^+ions (ii) do not register their activity on the electrode. The activity of free H^+ions in true solutions of acids would not be altered to any such extent on the addition of the salt. This is shown by the control experiment on the H^+ion activity of a hydrochloric acid solution having nearly the same *p*H as the sol (Fig. 1).

Taken in conjunction with the ultrafiltration experiments on sols H and P the observed large variations of H^+ ion activity recorded in Table V arise at least in part from a displacement of osmotically inactive H^+ions from the colloidal particles.

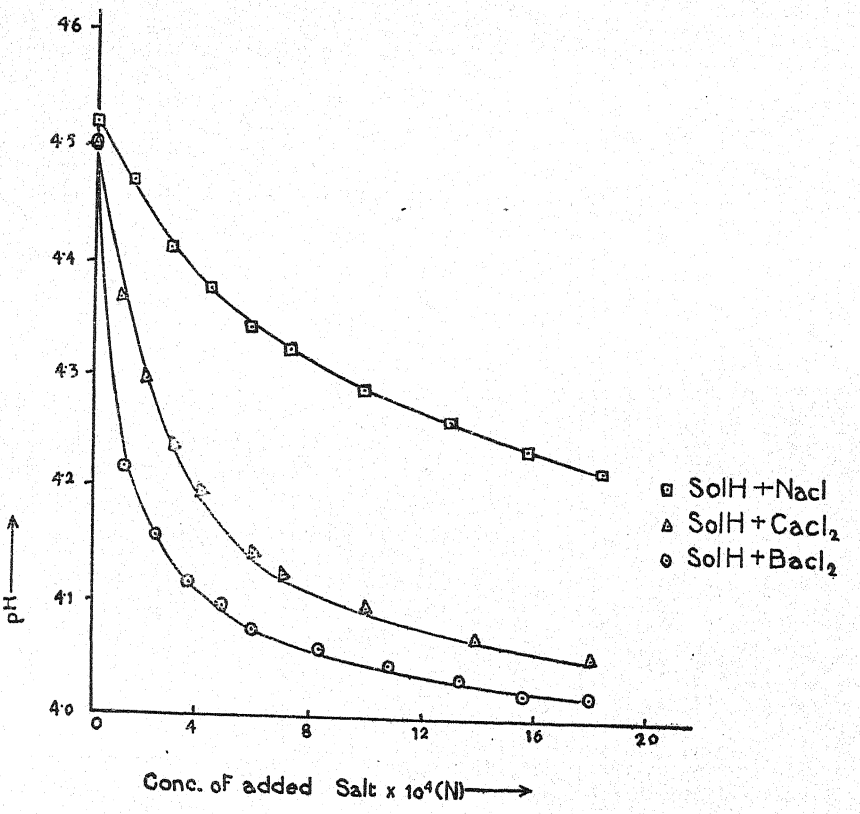


FIG. 2

Aluminium ions displaced from hydrogen clays and acid soils by neutral salts are known to contribute to the observed free and total acids of the neutral salt extracts* [Paver and Marshall, 1934]. The following results show that such aluminium ions cannot wholly account for the observed free and total acids of the supernatant liquids above the coagula of hydrogen clay sol + salt mixtures.

An exchange of osmotically inactive H^+ions associated with the colloidal particles of the sols for the cations of the salt has to be assumed in order to explain the much larger free and total acids of the ultrafiltrates of the sol + salt mixtures compared to those of the ultrafiltrate of the sol itself.

* This topic is being systematically studied by Mr B. Chatterjee in this laboratory.

TABLE VI

System	*p*H	Free acid (gm. ions of H per litre)	Total acid at inflexion point of titration curve with NaOH		Al in ultrafiltrate (milli-equivalents per 100 gm. colloid)
			1 Equivalents per litre	1 Millie-quivalents per 100 gm. colloid	
Sol P . . .	4·54	$2·9\times10^{-5}$	200×10^{-5}	82·0	..
Ultrafiltrate of sol P	5·85	$1·4\times10^{-6}$	*Nil*	*Nil*	..
Ultrafiltrate of sol P + ·01*N* NaCl (curve I, figure 2 *a*).	3·66	$2·2\times10^{-4}$	$2·4\times10^{-4}$	10	0·5
Ultrafiltrate of sol P + ·04*N* NaCl (curve II, figure 2*a*).	3·30	$5·0\times10^{-4}$	$4·6\times10^{-4}$	19	3·0
Solution of aluminium chloride* (curve III, Fig. 2*a*).	3·22	$6·0\times10^{-4}$	$1·26\times10^{-1}$	..	..

The titration curves of the ultrafiltrates of the sol+salt mixture given in Fig. 2(*a*) are characteristic of a dissolved strong acid, viz., hydrochloric acid, formed by the interaction between the hydrogen clay and the neutral salt, sodium chloride.

The curves have a different form compared with that of a solution of aluminium chloride given in the same figure. The strong acid character of the titration curves of the ultrafiltrates harmonizes with the result (Table VI) that they have nearly the same free and total acids expressed in normality. The solution of aluminium chloride, on the other hand, has very different free and total acids.

Table VI shows that at the higher concentration of the salt the displaced aluminium forms a larger part of the total acid of the ultrafiltrate. Similar observations have been made by Paver and Marshall [1934] and by B. Chatterjee in this laboratory.† They will be fully dealt with in a future publication.

* From unpublished work by Mr N. P. Datta in this laboratory

† Unpublished work

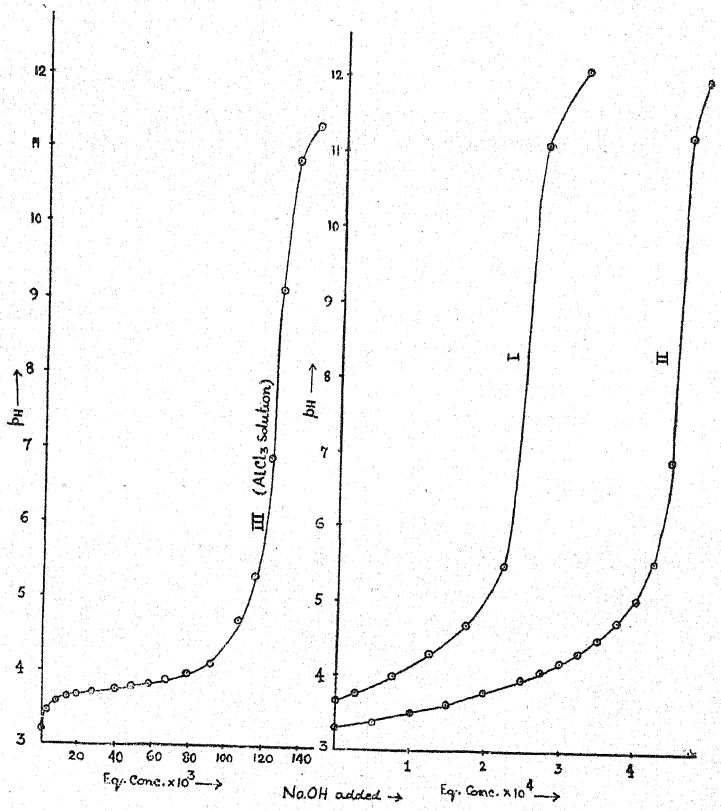


FIG. 2(*a*)

The following results obtained with sol P show that by repeated treatment of the sol with a solution of sodium chloride at a sufficiently low concentration (0·005*N*), increasing amounts of H^+ions can be displaced from the colloidal particles of the sol though practically no Al^{+++}ions are found in the salt extracts.

Theoretically it is not impossible that if the leaching is sufficiently continued an amount of H^+ions comparable to the total acid of the sol calculated at the inflexion point of its titration curve with a base (e.g. NaOH) will be displaced from the colloidal particles. The incomplete displacement of the H^+ions by the cation of the salt is obviously to be referred to the balanced nature of the reaction which can be schematically represented as $\boxed{\text{clay}}\ H + NaCl \rightleftharpoons \boxed{\text{clay}}\ Na + HCl$.

The incomplete displacement is due to the back reaction whose intensity at any stage of the leaching depends on the concentration of free H^+ions in

the intermicellary liquid. This concentration decreases as the leaching proceeds thus favouring more and more the direct reaction. In the interaction with a base to be discussed later the back reaction is absent thus securing a more complete replacement of the H^+ions of the colloidal particles by the cations of the base though the cations may be at a much lower concentration than in the case of the neutral salt solution.

TABLE VII

System	Total acid in m. e. per 100 gm. colloid*
Sol P	82·0
1st leachate (0·5 gm. of clay+200 c.c. of 0·005*N* NaCl solution)	9·0
2nd leachate (50 c.c. solution)	2·0
3rd leachate ,, ...	1·8
4th leachate ,, ...	2·0
5th leachate ,, ...	1·8
6th leachate ,, ...	2·0

* Calculated at inflexion point of potentiometric titration curve with NaOH.

IV. INTERACTIONS OF COLLOIDAL SOLUTIONS OF HYDROGEN CLAYS WITH BASES : THE NATURE OF THE TITRATION CURVES

In part V of this series [Mitra, 1936] the nature of the potentiometric titration curves of a number of hydrogen clay sols with bases has been discussed. In this paper, both potentiometric and conductometric titration curves obtained under diverse conditions of titration have been examined including detailed analyses of their slopes and buffer capacities in different *p*H regions. Such systematic studies are likely to throw considerable light on the nature of the acid-base interaction in soil. They have been seldom undertaken in the past. Reference may, however, be made to Knight [1920], Jensen [1929], Hardy and Lewis [1929] and others who obtained titration curves

of soils mainly in connexion with the estimation of the lime requirement, or the degree of saturation of soil.

1. *Potentiometric titration curves of hydrogen clay sols with different strong bases*

Figs. 3*, 4, and 5 give the titration curves of hydrogen clay sols E, G and H obtained on titrating them with sodium, barium and calcium hydroxides.

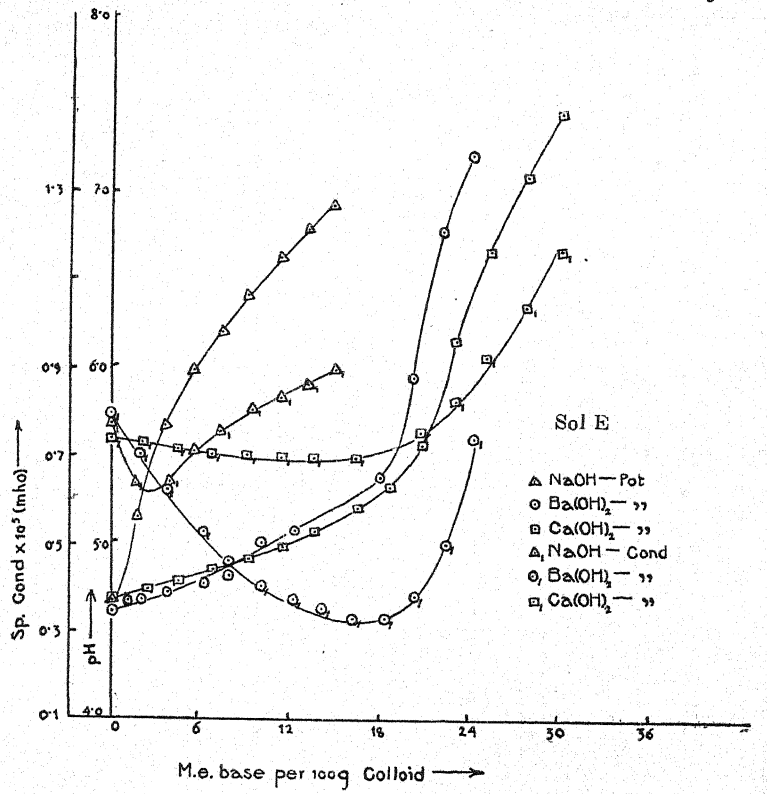


FIG. 3

The forms of the curves with the different bases are different. The potentiometric titration curves with baryta and calcium hydroxide indicate an apparent strong monobasic acid character of the sols. There is an initial flat portion followed by a steeper region which shows an inflexion point. The slope gradually diminishes after the inflexion point has been passed. Baver [1930] observed an initial sharp rise in the potentiometric titration curves of hydrogen clay sols with the above bases and from this observation he attributed a week monobasic acid character to the sols studied by him [cp. Bradfield, 1923].

The strong monobasic acid character of the potentiometric titration curves with barium and calcium hydroxides cannot be referred to the neutralization of any dissolved acid or acids present in the sol as its ultrafiltrate contains

*Rep oduced from Fig. 1 of part V of this series.

negligible free and total acids (Table II). A difference from a true monobasic acid character, however, exists. Thus the free acidity of sol G, for example, is only 6·5 per cent of its total acid even at a total acid concentration of the order of $10-^{4}N$. On analogy with an acid in true solution, the sol is very weakly dissociated. The potentiometric titration curve of the sol with baryta, however, (Fig. 4), does not show the sharp initial rise characteristic of a week acid in true solution.

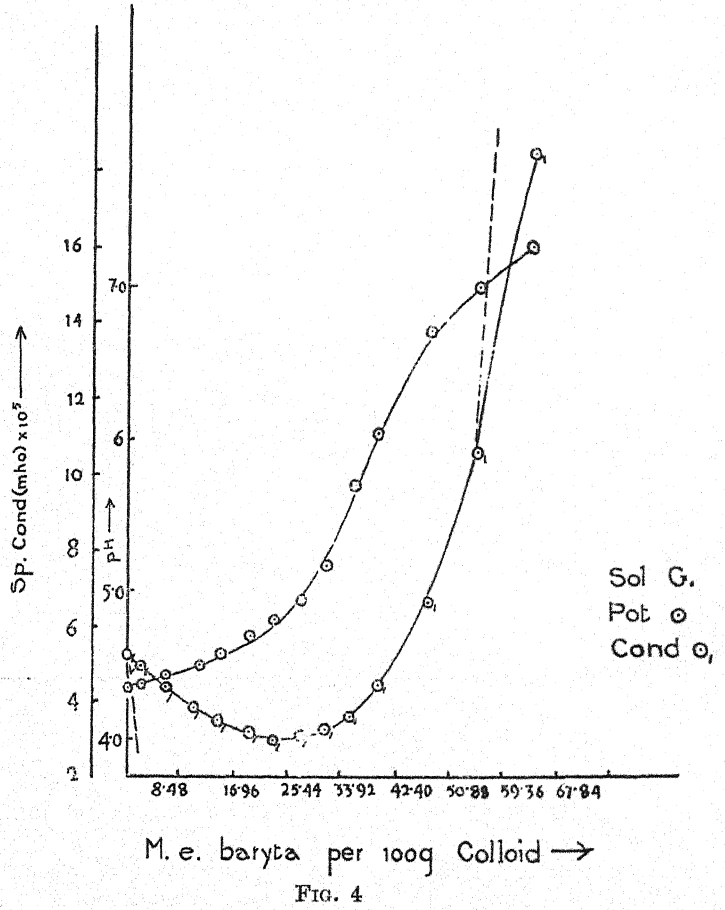


FIG. 4

The potentiometric titration curves with caustic soda show a comparatively sharp initial rise indicating a relatively weak acid character of the sols. This initial rise is followed by a gradual flattening of the curve, that is by a region of continued and increasing buffer action. No inflexion point in the alkaline region characteristic of a weak acid in true solution is, however, observed in the curves of sols E and H up to the point to which the titration had been extended. There is thus an important difference from a true weak acid character although a consideration of the comparatively sharp initial rise alone would justify the conclusion that a weak acid is being titrated.

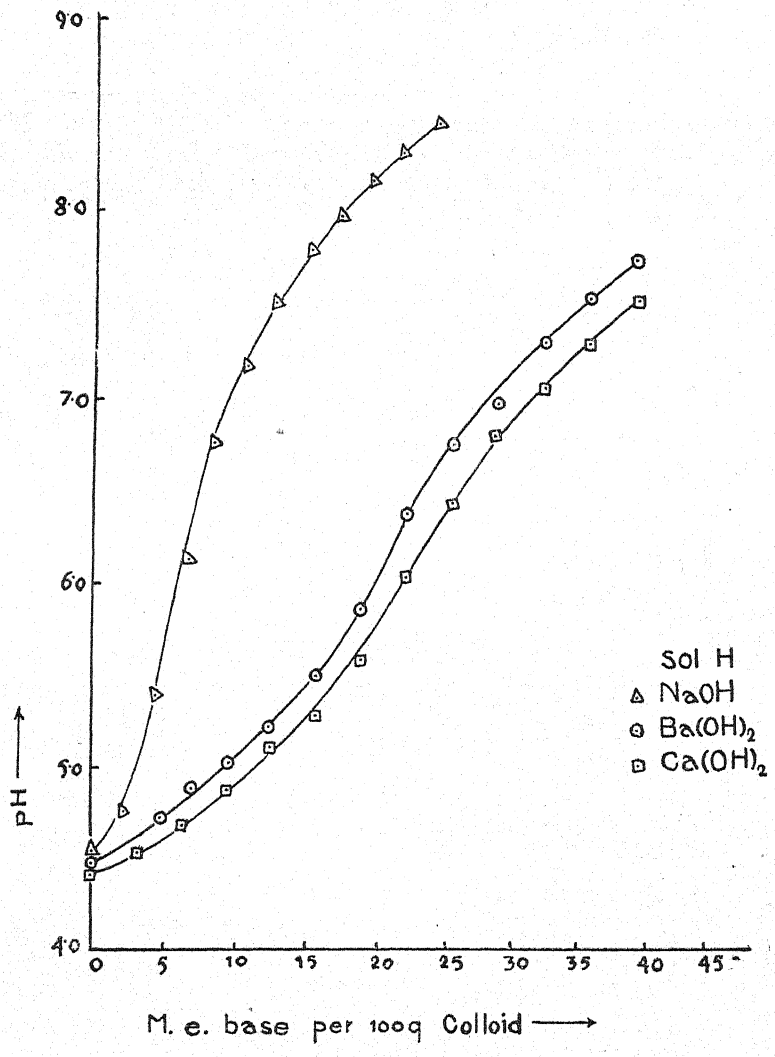


FIG. 5

Compared to sols E and H, the caustic soda titration curves of sols I and K given in Figs. 6 and 7 closely resemble those of a weak acid in true solution in that they have definite inflexion points in the alkaline region.

Sols I and K differ from sols E and H in one important respect. The silica-alumina ratios of their colloidal material are considerably greater than those of sols E and H as the following figures will show.

TABLE VIII

	Colloidal material of sol			
	E	H	I	K
SiO_2/Al_2O_3 (molar)	2·65	2·37	3·87	3·40

A closer examination of the slopes of the caustic soda titration curves of sols I and K and of their buffer capacities show, further, that the weak monobasic acid character indicated by them is only apparent. Thus the *p*H at the point of half neutralization in the caustic soda titration curve of sol I is 6·05 which corresponds to a dissociation constant of $8 \cdot 91 \times 10^{-7}$. In Fig. 8 the theoretical titration curve of a monobasic acid having this dissociation constant and the total acidity corresponding to the inflexion point of sol I has also been given for comparison.

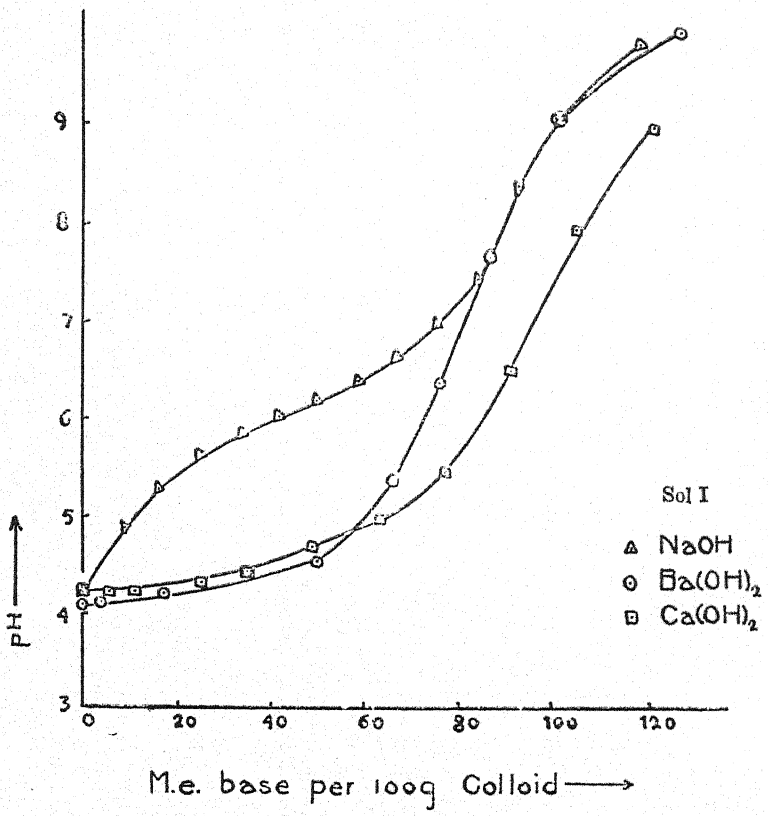


FIG. 6

The theoretical curve has been obtained with the aid of the equation

$$[H] = K.\frac{a-b-[H^+]+[O\bar{H}]}{b+[H^+]-[O\bar{H}]}$$

where a represents the total acid, b the concentration of the base and K the dissociation constant. The theoretical titration curve definitely differs from the actual titration curve. A comparison of the buffer capacities* which are

*The buffer capacity considered here is the reciprocal of the slope of the potentiometric titration curve and is given by the expression (van Slyke : *J. Biol. Chem.*, **22**, p. 525, 1922) $\frac{2 \cdot 302.a.K.[H^+]}{(K+[H])^2}$ where (a) is the total acidity and K, the dissociation constant.

also shown in Fig. 8 confirms the difference between the two curves specially after the inflexion point has been passed. The sol has a higher buffer capacity than the corresponding hypothetical acid. It is evident that the sol has definitely different properties than what are expected of a corresponding weak monobasic acid in true solution.

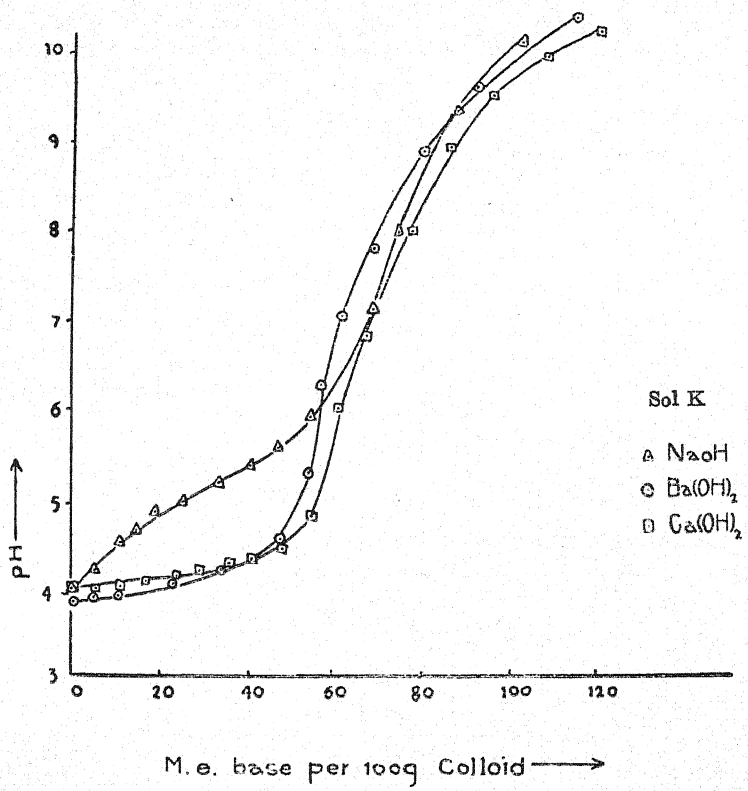


FIG. 7

The baryta and calcium hydroxide titration curves of sols I and K show, as in the case of sols E and H, an apparent strong monobasic acid character.

The titration curves with the different bases yield different total acidity values calculated from their inflexion points. These variations of the total acid have been discussed in detail in the previous paper of this series. Attention should, however, be drawn here to an interesting difference between sols E and H on the one hand and sols I and K on the other, in respect of the order of total acidities obtained on titration with different bases. With sols E and H, the total acid follows the order : $Ca(OH)_2 > Ba(OH)_2 > NaOH$. The NaOH titration curves of sols I and K, however, give total acidity values (calculated at the inflexion points) which are somewhat greater than those obtained from their baryta and calcium hydroxide titration curves. This is brought out by Table IX.

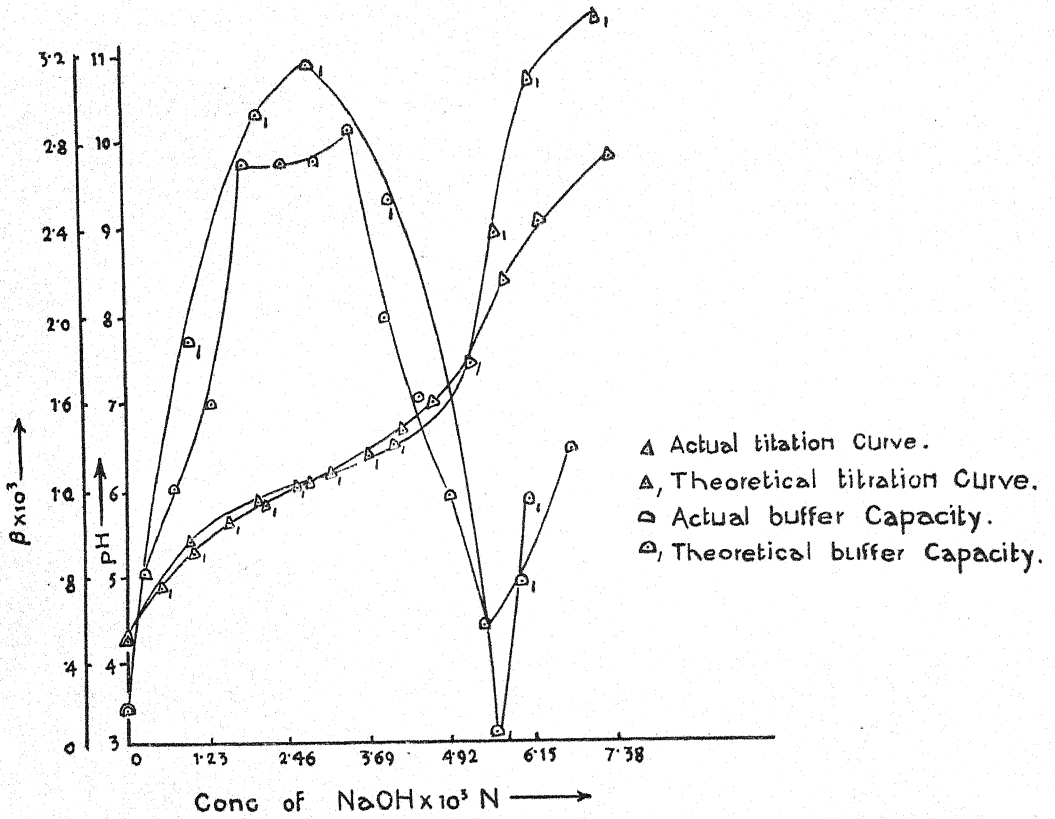


FIG. 8

TABLE IX

Sol	Base used for titration	*p*H at inflexion	Total acid in m.e. base per 100 gm. colloid	
			At inflexion pt.	At *p*H 7·0
E	NaOH	5·4	2·2	15·4
	$Ba(OH)_2$	6·0	20·6	25·0
	$Ca(OH)_2$	5·8	21·5	26·2
H	$Ba(OH)_2$	5·8	21·5	32·0
	$Ca(OH)_2$	6·6	21·5	32·8
I	NaOH	8·05	90·0	78·0
	$Ba(OH)_2$	7·00	82·0	82·0
	$Ca(OH)_2$	6·95	96·0	97·0
K	NaOH	7·15	68·0	67·0
	$Ba(OH)_2$	5·80	55·0	61·0
	$Ca(OH)_2$	5·20	58·0	67·0

In comparing the total acid at the inflexion points in the titration curves with different bases, the location in the *p*H scale of such inflexion points has to be considered for, as was shown in the previous part of this series, the higher the *p*H the greater is the amount of the acid reacting with the base. The greater total acid (at the inflexion point) with NaOH than with $Ba(OH)_2$, or, $Ca(OH)_2$ observed in the case of sols I and K is due to the inflexion points in the NaOH curve occurring in the alkaline region which is not the case with the $Ba(OH)_2$, or, $Ca(OH)_2$ curves. The titration curves of sols E and H do not show such features. An examination of the slopes of the titration curves of sols I and K with different bases shows the same order of the capacity of these bases to react with sols I and K as observed with sols E and H. The order is : $Ca(OH)_2$ $>Ba(OH)_2>NaOH$.

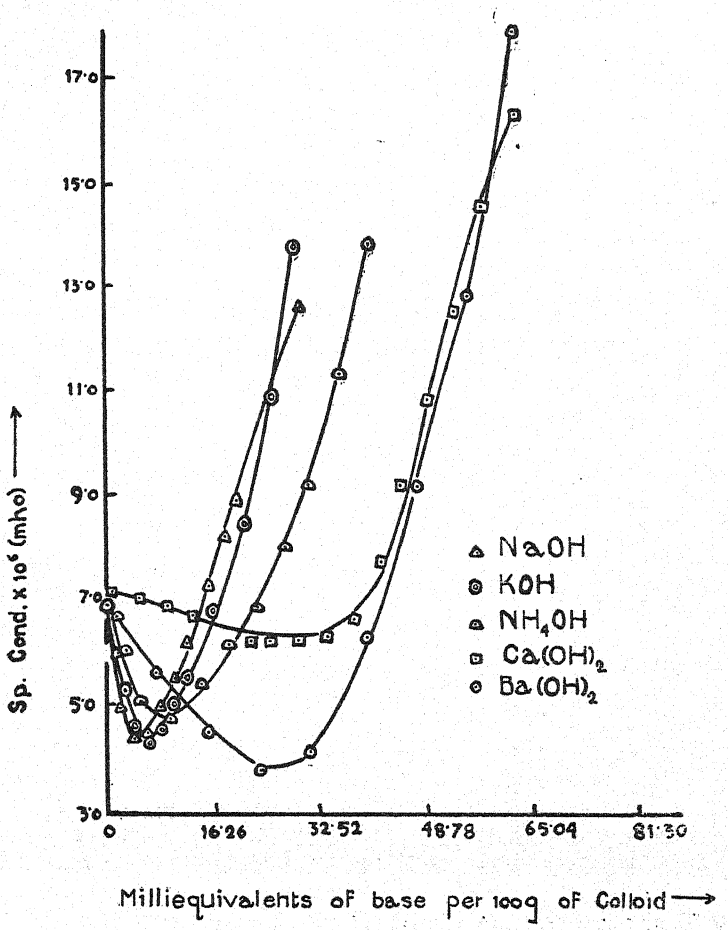


FIG 9.

2. *Mutually conflicting features of the potentiometric and conductometric titration curves of hydrogen clay sols*

The conductometric titration curves of hydrogen clay sols with different bases present certain features which are entirely at variance with those of the

corresponding potentiometric titration curves. No reference to such discrepancies is found in the existing literature.

The potentiometric titration curve of sol E with caustic soda shows an initial weak acid character while the corresponding conductometric curve (Fig. 3) has a sharp minimum (more sharp than the minimum of the baryta or calcium hydroxide titration curve) and in this respect indicates a strong acid character of the sol. Baver [1930], however, observed an initial rise of the specific conductivity on titrating a hydrogen clay sol with caustic soda. This was obviously due to too much alkali being added at the very first instalment, the initial lowering of the specific conductivity and the minimum point being thus missed.

The conductometric titration curves of sols E and H with baryta and calcium hydroxide have round or flat minima and in this respect indicate, in contrast to the corresponding potentiometric titration curves, a comparatively weak acid character of the sols.

Fig. 9 offers an interesting comparative study of the conductometric titration curves of hydrogen clay sol F with sodium, potassium, ammonium, clacium and barium hydroxides.

The slopes of the descending and part of the ascending portion of the curve obtained on titrating with $Ca(OH)_2$ is distinctly less than that of the curve with $Ba(OH)_2$. The slopes are arranged in the order : $NaOH > KOH > NH_4OH > Ba(OH)_2 > Ca(OH)_2$ as the following figures will show :

TABLE X

Base used	Slope of initial descending portion	
	obs.	Calc.
NaOH	0·100	0·346
KOH	0·085	0·318
NHO_4H	0·045	0·315
$Ba(OH)_2$	0·018	0·330
$Ca(OH)_2$	0·003	0·335

The NaOH curve has the greatest downward slope and in this respect shows a stronger acid character than the $Ba(OH)_2$, or, the $Ca(OH)_2$ curve. As already shown, however, the potentiometric titration curves with these bases give an altogether different picture regarding the acid character of the sols.

Table X shows that the actual slopes of the descending portions of the conductometric curves are smaller than those calculated* for a strong acid.

*The slope is given by $(U_{H+}—U_M)/1000$, where U_{H+} and U_M are respectively the mobilities of hydrogen ion and the cation of the base at 35°C. at which all measurements were carried out.

The greatest discrepancy is observed with the $Ba(OH)_2$ and $Ca(OH)_2$ curves.

3. *The variability of the total neutralizable acid of colloidal solutions of hydrogen clays*

Reference has already been made to variations of the total acid of a hydrogen clay sol obtained on titration with different bases. In part VI of this series [Mitra, Mukherjee and Bagchi, 1940] these variations of the total acid have been fully reported and it has been shown that titration of the sol with a given base in the presence of a large concentration of a neutral salt yields a higher total acid, measured at the same *p*H, than titration with the base alone. Such variations would not be possible in the case of any dissolved acid.

V. The 'degrees of dissociation' and 'dissociation constants' of colloidal solutions of hydrogen clays

If colloidal solutions of hydrogen clays could be treated as acids in true solution their degrees of dissociation at a given total acid concentration and dissociation constants calculated from their titration curves would give an estimate of their ' strength ' as acid systems.

The degree of dissociation of a hydrogen clay sol at a given total acid concentration may be taken for purposes of discussion as equal to the ratio of the free acidity (i.e. the hydrogen ion concentration calculated from the observed *p*H) to the amount of acid equivalent to that of a dilute base necessary to reach the inflexion point. The following table gives degrees of dissociation of hydrogen clay sols E, F and H.

Table XI

Sol	Base used for the titration	*p*H	H ion conc. $\times 10^5 N$	Total acid at inflexion point $\times 10^5 N$	Free acidity $\times 100$ / Total acidity
E	NaOH	4·66	2·19	2·6	84·2
	$Ba(OH)_2$			24·3	9·0
	$Ca(OH)_2$			25·0	8·4
F	NaOH	14·4	3·89	12·0	32·4
	$Ba(OH)_2$			38·0	10·1
H	NaOH	4·52	3·02	14·0	75·00
	$Ba(OH)_2$			99·0	3·03
	$Ca(OH)_2$			99·0	3·03

The degree of dissociation has a surprisingly low value when baryta or calcium hydroxide is used for the titration although the total acid concentration is of the order of $10^{-4}N$. The sol thus behaves as a very weak acid. The corresponding potentiometric titration curves indicate, on the other hand, a strong acid character of the sols as already pointed out.

Table XI shows, however, that much higher values of the degree of dissociation are obtained when the total acid given by the inflexion point, or minimum of the caustic soda titration curve, is used for the calculation. This is in agreement with the strong acid character of the conductometric titration curves with caustic soda (Fig. 4) but is at variance with the comparatively weak acid character of the corresponding potentiometric titration curve. The differences in the values of the degree of dissociation arise obviously from the variations of the total acidity of the sols previously mentioned.

The apparent dissociation constants of hydrogen clay sols E, I and K have also been claculated. Two series of values of the dissociation constant have been obtained and tabulated below as K and K' values. The K values were calculated from the equation $K = \frac{\alpha_C^2}{1-\alpha}$ where α is the ratio of the free acid to the total acid (C). The K' values were calculated from different points in the potentiometric titration curves using the equation $p\mathrm{H} = p\mathrm{K}' + \log \frac{[\text{salt}]}{[\text{acid}]}$; [salt], at any stage, has been taken as equivalent to the concentration [B] of the base added and [acid] has been taken as equal to C –[B].

TABLE XII

Sol	Base used for titration	K	K'		
			1/4 neutralization	1/2 neutralization	3/4 neutralization
E	$Ba(OH)_2$.	$2{\cdot}2\times10^{-6}$	$1{\cdot}4\times10^{-5}$	$2{\cdot}8\times10^{-5}$	$5{\cdot}0\times10^{-5}$
	$Ca(OH)_2$.	$2{\cdot}0\times10^{-6}$	$5{\cdot}0\times10^{-6}$	$1{\cdot}0\times10^{-5}$	$1{\cdot}7\times10^{-5}$

TABLE XIII

Sol	Base used for titration	K	K′		
			1/4 neutralization	1/2 neutralization	3/4 neutralization
I	NaOH .	$7{\cdot}3\times10^{-7}$	$8{\cdot}9\times10^{-7}$	$7{\cdot}9\times10^{-7}$	$8{\cdot}0\times10^{-6}$
	$Ba(OH)_2$.	$8{\cdot}9\times10^{-7}$	$2{\cdot}5\times10^{-5}$	$3{\cdot}7\times10^{-5}$	$3{\cdot}5\times10^{-5}$
	$Ca(OH)_2$.	$6{\cdot}5\times10^{-7}$	$2{\cdot}2\times10^{-5}$	$2{\cdot}4\times10^{-5}$	$2{\cdot}2\times10^{-5}$
K	NaOH .	$6{\cdot}7\times10^{-7}$	$5{\cdot}6\times10^{-6}$	$5{\cdot}3\times10^{-6}$	$4{\cdot}2\times10^{-6}$
	$Ba(OH)_2$.	$8{\cdot}9\times10^{-7}$	$4{\cdot}4\times10^{-5}$	$7{\cdot}0\times10^{-5}$	$1{\cdot}0\times10^{-4}$
	$Ca(OH)_2$.	$8{\cdot}5\times10^{-7}$	$3{\cdot}9\times10^{-5}$	$6{\cdot}3\times10^{-5}$	$1{\cdot}0\times10^{-4}$

Tables XII and XIII show that there is no agreement between the K and K' values especially for the baryta and calcium hydroxide titrations. Also, the values of K' for them are much larger than those for the caustic soda titrations. This is again in agreement with the strong acid character of the baryta and calcium hydroxide titration curves (potentiometric) compared to the weak acid character of the caustic soda curves (potentiometric). Actually, the ' dissociation constants ' given in tables XII and XIII are not constants in any real sense of the term and consequently they lose their significance.

VI. The role of the electrical double layer and of adsorption of ions in the interactions of colloidal solutions of hydrogen clays with bases and salts

The results given in the preceding sections show that the interactions of hydrogen clay sols with electrolytes present a number of special features which are difficult to reconcile in the light of classical electrochemistry. A much clearer elucidation of these special features can, however, be obtained on the basis of the theory of the electrical double layer postulating the existence of primarily adsorbed ions associated with the colloidal particles of the sol and of a secondary adsorption of cations by them [Mukherjee, 1921, 1922]. Mukherjee, Mitra and Mukherjee [1937] have used this theory as the basis of a theoretical formulation of the interactions of colloidal acid systems including hydrogen clay sols. An outline of the theory has been given in the previous paper of this series [Mitra, Mukherjee, and Bagchi, 1940] where it has been applied to explain the variations of the total neutralizable acids of hydrogen clay sols observed on estimating the acid under different conditions of titration. An explanation of the special features of hydrogen clay sols recorded in this paper is given below based on the above theory.*

According to the theory, H^+ ions corresponding to the primarily adsorbed anions ' built in ' on the solid side of the solid-liquid interface exist in two states, viz. in a secondarily adsorbed condition either by electrostatic, or, specific forces and in a free, or, ' mobile ' state. The H^+ ions of the first category are osmotically inactive. They are the ' bound ' H^+ ions. Both ' mobile ' and ' bound ' H^+ ions may be displaced by the cations of an added salt, or, a base, the displacement being determined by the adsorbability of the cations given by their valency, mobility and state of hydration when the cations are adsorbed by electrostatic forces of attraction. They may also be adsorbed by specific valence forces, or forces of the Van der Waals' type.

The mobile H^+ ions give rise to the free acidity, i.e. the observed H^+ ion activity of the sol while its total acidity calculated from the inflexion point of its titration curve with a base includes both ' mobile ' and ' bound ' H^+ ions. With the sols used in this work, the ' bound ' H^+ ions far outnumber the ions of the other category as the small ratio of the free to total acids of the sols shows.

*The picture here suggested is of a general nature and it takes no account of (*a*) the detailed mineralogical structure of hydrogen clays, (*b*) their amphoteric character and (*c*) the role of Al^{+++} and other ions on the surface in addition to H^+ ions. Investigations covering these aspects are in progress.

Though osmotically active, the ' mobile ' H^+ ions are not present in the intermicellary liquid of the sol which explains the negligible free and total acids of the ultrafiltrate of the sol compared to those of the sol itself. The colloidal particles of the sol with their adsorbed H^+ ions—mobile and bound—constitute a distinctly separate phase from the intermicellary liquid.

On the addition of a neutral salt to the sol, only the mobile H^+ ions, or both mobile and bound H^+ ions, may be displaced by its cations. The alkali metal cations are weakly adsorbed. Consequently, when a salt containing an alkali metal cation is added to the sol, a displacement of the mobile H^+ ions only may take place specially if the salt is added in very low concentrations. As only a displacement of hydrogen ions which were previously in an osmotically active condition is involved, no marked variation of the hydrogen ion activity of the sol will be observed. The results given in table IV illustrate this effect. Though the H^+ion activity of the sol has not appreciably changed, that of its ultrafiltrate has considerably increased. This increase is the result of the interchange between the mobile H^+ ions in the double layers and the alkali metal cations in solution.

A displacement of the bound H^+ ions will cause an increase in the H^+ ion activity of the sol. The results given in table V show that using chlorides alone, the relative effects of the different cations in increasing the H^+ion activity follows the order $Ba^{++} > Ca^{++} > Na^+$ which is the order of their electrical adsorption. In the previous paper of this series [Mitra, Mukherjee, and Bagchi, 1940] it has been shown that the relative effects of the cations to increase the total neutralizable acid of the sol follow the same order which is also in agreement with the usual lyotrope series. It appears, therefore, that in the interactions of hydrogen clays with neutral salts an electrical adsorption of the cations of the salt plays a dominant role. The resulting cation effect is thus determined by electrical factors alone and it may consequently be designated as the *' regular cation effect '*.

In the interactions of hydrogen clays with bases also, adsorption of the cations of the base plays a definite role. On the addition of a base, besides the direct neutralization of the H^+ by the OH^- ions, the cations of the base displace some of the bound H^+ ions from the double layer which are then neutralised by the OH^- ions. The greater the adsorbability of the cation, the greater is this displacement and hence a larger amount of acid is neutralized at a given *p*H. The smaller total acidity obtained on titration with sodium hydroxide compared to barium and calcium hydroxides is thus explained. The total acid calculated at a fixed *p*H decreases in the order $Ca(OH)_2 > Ba(OH)_2 > NaOH$. In the interactions of the sols with the bases, therefore, the Ca^{++} ions appear to have a greater relative effect than the Ba^{++} ions. The slopes of the titration curves point to the same relative effects of the cations. Here, therefore, we have an *' irregular ' or ' specific cation effect '* in the sense that it does not follow the lyotrope series. Unlike the regular cation effect previously discussed it does not result from simple electrical adsorption of the cations together with their hydrated envelopes but arises from their adsorption in the dehydrated condition by specific forces other than simple electrostatic forces.

The features of the titration curves are explained from similar considerations. The first additions of the base neutralize the mobile H^+ ions. The disappearance of these mobile H^+ ions displaces the equilibrium between mobile and bound H^+ ions in the double layer which is restored by the passage of some bound H^+ ions from the bound to the mobile condition. Adsorption of the cations of the base considerably facilitates this process. When barium or calcium hydroxide is the base used for the titration, the Ba^{++} or Ca^{++} ions, because of their high adsorption, displace more and more bound H^+ ions from the beginning of the titration which are then neutralized by the OH^-ions of the base. The titration curve (potentiometric) has, therefore, a flat run indicating a moderately strong acid character of the sol. When the limit to which the bound H^+ ions can be so displaced and neutralized has been reached, further addition of the base results in a sharp rise of the *p*H, that is, the titration curve shows an inflexion point. This limit, however, does not correspond to the neutralization of all the bound H^+ ions as the titration curve shows a continued buffer action beyond the inflexion point. The inflexion point thus indicates the neutralization of H^+ ions in a definite affinity level.

Using sodium hydroxide also, the first additions of the base neutralize the mobile H^+ ions. The bound H^+ ions which far outnumber the mobile H^+ ions cannot be displaced from the double layer by the sodium ions because of their weak electrical adsorption. The *p*H of the system, therefore, shoots up and the titration curve shows a comparatively sharp initial rise. On further additions of the base, the concentration of sodium ions in the system increases and thus the probability of their adsorption is increased. This, combined with the gradually increasing *p*H of the system helps in the neutralization of more and more bound H^+ ions and the titration curve shows a flattening after the initial rise. When the limit to which the bound H^+ ions can be so displaced and neutralized has been reached further addition of the base may result in a sharp rise of the *p*H, that is, an inflection point in the titration curve may be observed (titration curves of sols I and K in Figs. 6 and 7).

A consistent explanation of the apparently contradictory features of the potentiometric and conductometric curves is also obtained on the assumption that the greater the electrical adsorbability of the cations of the base the greater is the amount of bound H^+ ions displaced from the double layer which can then react with the OH^-ions of the base. The greater the displacement of bound H^+ ions the smaller will be the slopes of the conductometric titration curves which will thus resemble those of a weak acid. The marked departure in the slopes of the $Ca(OH)_2$ and $Ba(OH)_2$ curves of sol F from those calculated for a strong acid and the weak acid character of these curves are thus explained. The process of displacement of bound H^+ ions and their subsequent neutralization would also diminish the slope of the potentiometric titration curve but in this case a smaller slope indicates a stronger acid. The caustic soda titration curve (conductometric) has the greatest downward slope though the corresponding potentiometric curve shows the steepest initial rise and thus the weakest acid character. The total acid calculated from the minimum of the NaOH curve agrees nearly (within 15 per cent) with the free

acidity of the sol. The minimum of the caustic soda curve thus corresponds mainly to the neutralization of the mobile H^+ ions and only a small fraction of the bound H^+ ions.

Summary

The electrochemical properties of a number of hydrogen clay sols have been studied.

While the sols have measurable free and total acids, their ultrafiltrates are practically neutral.

The actual specific conductivity of the sol is often less than that due to its free H^+ ions whose concentration has been calculated from the observed *p*H of the sol.

When a neutral salt is added to a hydrogen clay sol, its H^+ ion activity shows a marked increase. The nature and concentration of the cations of the salt are important factors. Using chlorides alone, the relative effects of cations follow the order $Ba^{++}>Ca^{++}>Na$ which is in agreement with the lyotrope series and thus illustrates a '*regular cation effect*'.

The sols give characteristic potentiometric and conductometric titration curves on titration with bases. The curves show several features which would not be expected with dissolved acids. The forms of the curves obtained on titration with different bases as also the total neutralizable acids of the sols calculated from them are different. The total acid decreases in the order $Ca(OH)_2>Ba(OH)_2>$ NaOH. The greater relative effect of $Ca(OH)_2$ compared to $Ba(OH)_2$ illustrates an '*irregular, or, specific cation effect.* Mutually conflicting features are shown by the potentiometric and conductometric titration curves with a given base The 'dissociation constants' calculated from the potentiometric curves have a fictitious significance. Somewhat different types of curves are obtained with hydrogen clays having widely different silica-alumina ratios.

The results have been discussed from the point of view of classical electrochemistry as also in the light of the theory of the electrical double layer and of adsorption of ions.

REFERENCES

Baver, L. D. (1930). *Soil Sci.* **29**, 291

Bradfield, R. (1923). *J. Amer. Chem. Soc.* **45**, 2669

Daikuhara, G. (1914). *Bull. Japan Imp. Centr. Agric. Exp. Sta.* **2**, 1

Gedroiz, K. K. (1924). *J. Expt. Agron.* **22**, 3

Hardy, F. and Lewis, A. H. (1929). *J. Agric. Sci.* **19**, 17

Hartley, G. S. (1935). *Trans. Far. Soc.* **31**, 31

Hissink, D. J. (1925). *Trans. Far. Soc.* **20**, 551

Hopkins, C. J. (1903). *U. S. Dept. Agric. Bar. Chem. Bull. No.* **73**

Jenny, H. (1932). *J. Phys. Chem.* **36**, 2217

———— (1936). *J. Phys. Chem.* **40**, 501

Jensen, H. L. (1929). *Int. Mit. für Bodenkunde* **14**, 112

Knight, H. G. (1920). *J. Ind. Eng. Chem.* **12**, 560

Marhsall, C. E. and Gupta, R. S. (1933). *J. Soc. Chem. Ind.* **58**, 433T

Mattson, S. (1932). *Soil. Sci.* **34**, 459

————(1935). *Ann. Agric. Coll. Sweden* **2**, 135

McBain, J. W. and Betz, M. D. (1935). *J. Amer. Chem. Soc.* **57**, 1912

Mitra, R. P. (1936). *Ind. J. Agric. Sci.* **6**, 555

Mitra, R. P., Mukherjee, S. K. and Bagchi, S. N. (1940). *Ind. J. Agric. Sci.* **10**, 303

Mukherjee, J. N. (1921). *Trans. Far. Soc.* **16**, 103

———— (1922). *Phil. Mag.*, **44**, 321

———— (1933). *Kolloid Zeit.* **62**, 257 ; **65**, 72

Mukherjee, J. N., Mitra, R. P. and Mukherjee, S. (1937). *Trans. Nat. Inst. Sci. Ind.* **1**, 227

Mukherjee, J. N., Mitra, R. P., Ganguli, S. and Chatterjee, B. (1936). *Ind. J. Agric. Sci.* **6**, 517

Paver, H. and Marshall, C. E. (1934). *J. Soc. Chem. Ind.* **53**, 750

Russell, E. J. (1932). *Soil Conditions and Plant Growth*, Sixth Edition, 194

Wiegner, G. (1931). *J. Soc. Chem. Ind.* **50**, 103T

Wiegner, G. and Pallmann, H. (1929). *Verhandlungen der zwieten Kommission und der Alkali-subkomission der Internationalen Bodenkundlichen Gesselschaft* S. 92

THE BASE BINDING CAPACITIES OF HYDROGEN CLAYS AS DETERMINED BY DIFFERENT METHODS, I*

BY

R. P. MITRA, D.Sc.†

AND

A. K. MITRA, M.Sc.

(*Physical Chemistry Laboratory, University College of Science and Technology, Calcutta*)

(Received for publication on 12 September, 1939)

THERE is an element of arbitrariness regarding the various routine methods for estimating the base binding, or, base exchange capacity of soil. The different alternative methods do not always give concordant results. The uncertainty mainly arises from the difficulty of an accurate and unequivocal definition of what constitutes the exchangeable hydrogen, or, the titratable acid of the soil. Unlike the estimation of acids in true solution, or, colloidal systems in which the various phases can be clearly defined the amounts of acids estimated by the different routine methods are often ill-defined. A precise knowledge of the nature of the interactions involved in the estimations is therefore desirable especially in order to render possible a satisfactory correlation of the mutually conflicting experimental observations.

The methods used by Hopkins [1903], Daikuhara [1914] and Gedroiz [1924] for the estimation of the lime requirement of soil are based on the liberation of acid by the interaction of an acid soil with a neutral salt. Several theories have been proposed to explain the nature of this interaction. Until recently, this interaction had been regarded by some [Joseph and Oakley, 1925], following Way [1852], to be an instance of double decomposition. It has also been suggested that on account of surface tension effects [Gedroiz, 1929] the neutral salt is split into the acid and the base of which the base is adsorbed at the interface and the corresponding acid is liberated. The difficulties in the way of a simple explanation is illustrated by observations such as those of Ramann [quoted by Hissink, 1935] that a complete displacement of all the reactive hydrogen ions of soil is not effected even by continued leaching of the soil with a salt solution. The problem is further complicated by the fact that aluminium ions are nearly always found in the neutral salt extracts of acid

*The results given in this paper have been taken from the published annual report for 1936-37 on the working of a 'Scheme of Research into the Properties of Colloid Soil Constituents' financed by the Imperial Council of Agricultural Research, India and directed by Professor J. N. Mukherjee. The authors' thanks are due to the University of Calcutta for permission to work in the Physical Chemistry Laboratories of the University and for other facilities.

†Senior Assistant Soil Chemist under the above scheme.

soils. The role played by the electrical double layer in these interactions has been mphasized by Mukherjee [1922] and Wiegner [1925]. The picture is however still far from being definite and according to Hissink [1935], no existing, theory can adequately explain the nature of the above interactions.

The method of electrometric titration with a base has often been used [Goy, Muller and Roos, 1928 ; Hardy and Lewis, 1929] for estimating the total neutralizable acid of soil, e.g. for assessing its lime requirement and exchangeable hydrogen. The nature of the interaction between an acid soil and a base cannot also be said to have been clearly understood. Also, an adequate explanation of the observation that more base is required to attain a certain *p*H when the soil is titrated in the presence of a neutral salt than when titrated alone [Crowther and Martin, 1925 ; Hardy and Lewis, 1929 ; Clark and Collins, 1930] has not been so far forthcoming.

In a series of papers being published from this laboratory [Mitra, 1936] the nature of the reactions between colloidal solutions of hydrogen clays and bases both in the presence and absence of neutral salts is being studied in detail. A theoretical formulation of the reactions in some simple systems related to hydrogen clays has been given by Mukherjee, Mitra and Mukherjee [1937]. The present paper being the first part of a series and its main purpose being to examine in the light of this theory the results of comparison of the base binding capacities of hydrogrn clays by different methods, the conclusions of Mukherjee, Mitra and Mukherjee [1937] as might be extended to hydrogen clay sols are discussed in some detail below.

The colloidal particles of the sols are surrounded by hydrogen ions existing partly in a free, or, osmotically active condition forming the mobile sheet of an electrical double layer and partly in a secondarily adsorbed state on the surface. The osmotically active hydrogen ions give rise to the observed hydrogen ion activity of the sol ; the remaining hydrogen ions are present in a ' bound ', that is, osmotically inactive condition.

In the interaction of the sol with a neutral salt, its cations displace hydrogen ions from the double layer, the amount of displacement depending on the adsorbability of the cations. Where Van der Waal's forces or chemical valence forces do not operate between the oppositely charged ions in the pairs formed by adsorption, the energy of adsorption is determined by their electrical properties, e.g. valency and mobility and the condition of hydration of the ions forming the ion pairs. Consequently, on the addition of different neutral salts having a common anion at the same concentration, the hydrogen ion activity of the sol increases according to the order $Ba^{++} > Ca^{++} > K^{+} > Na^{+}$ of the electrical adsorption of the hydrated cations which is also in agreement with the lyotrope series. This has been called a *regular cation effect.*

In interactions with bases also, the cations of the latter have a marked effect. Apart from the direct neutralization of the free hydrogen ions by hydroxyl ions, the cations of the base displace various amounts of bound hydrogen ions from the double layer which are then neutralized by the OH^- ions. The greater the displacement the greater is the amount of acid reacting with the base at a given *p*H. Titration with different bases thus yields different total acids calculated at a fixed *p*H. The total acid decreases in the order $Ca(OH)_2 > Ba(OH)_2 > NH_4OH > KOH > NaOH$. In the alkaline region

calcium appears to act more intensely than barium and this has been attributed to what has been called the *irregular cation effect* (*vide* later, p. 347) to distinguish it from the *regular cation effect.*

On titrating a hydrogen clay sol with a given base in the presence of a neutral salt, the cations of the salt present in large numbers, displace hydrogen ions from the double layers and thus bring into a neutralizable condition hydrogen ions present in higher affinity levels in the double layers than those which can be neutralized at the same *p*H by the base alone.* A greater total acidity is thus obtained on titration in the presence of the salt than in its absence. This explains why in the electrometric titration of soil more base is required to attain a certain *p*H when the titration is carried out in the presence of a salt than in its absence.

Actually, the total acid is a function of (1) the *p*H at which it is measured and (2) cation effects. In the absence of a salt, the first additions of the base neutralize mainly the mobile hydrogen ions and the *p*H rises. The equilibrium between mobile and bound hydrogen ions is disturbed and more hydrogen ions pass from the bound to the mobile condition. These hydrogen ions are then neutralized. The process continues as the *p*H rises and increasing amounts of the acid are neutralized. Adsorption of the cations of the base as previously explained facilitates this process and here the cation effect comes in. The cation effect finds expression in the different total acidities, measured at the same *p*H, obtained on titration with different strong bases. In titrations in the presence of a salt, the cation effect is much more marked in view of the large concentration of cations present in the system from the beginning of the titration. The sol+salt mixture contains free hydrogen ions displaced into the intermicellary liquid from the double layers by the cations of the salt and it has been definitely established that the particles in the flocs also contain amounts of hydrogen ions in a reactive condition.** In titrating this mixture, the free hydrogen ions in the supernatant liquid and surrounding the flocs are first neutralized and then as the *p*H rises more and more hydrogen ions are displaced from the flocs and neutralized. The large number of cations present in the system materially helps this process and the cation effect is emphatically brought out in the larger total acidity, measured at the same *p*H, obtained on titrating the sol+salt mixture than the sol alone. The hydrogen ions which are brought into a neutralizable condition on the addition of a neutral salt are not all displaced in the intermicellary solution. This is shown by the fact that the titration of the colloid-free extract obtained by continued leaching of the sol with the solution of the salt yields a much smaller total acid than that obtained on titrating the sol+salt mixture *in situ*. This observation is in agreement with that of Ramann already referred to and it shows that lime requirement methods in which the acid displaced in neutral salt extracts of soils is titrated estimate only a part of the total neutralizable acid of soil.

*The cations of the salts also displace Al^{+++} ions whose salts by hydrolysis give rise to some titratable acid in the sol + salt mixture. A systematic study of this point is being carried out in this laboratory by Mr B. Chatterjee.

**_Vide_ above footnote.

Reference has been made above to the relative effects of Ba^{++} and Ca^{++} ions in the interactions of their salts and bases with hydrogen clays and their dependence on the *p*H of the system. Added as salts, barium ions have a greater effect than calcium ions in liberating acid from hydrogen clays. Both the hydrogen ion activity and the total acidity of a hydrogen clay sol are increased to a greater extent on the addition of barium chloride than of calcium chloride. The interaction with the salts results in the liberation of acid and takes place in the acid region. The relative effects of the Ba^{++} and Ca^{++} ions in this region follow the electrical adsorption of hydrated ions and thus constitute a *regular cation effect*. But the total acid obtained on titration in the absence of a neutral salt of the cation with calcium hydroxide is, as already observed, usually greater than that obtained on titration with baryta. The Ca^{++} ions thus have a greater effect than the Ba^{++} ions. The slopes of the titration curves point to the same conclusions. An *irregular*, or, *specification effect*, that is, one which does not follow the lyotrope series and is determined by specific forces other than simple electrostatic attraction on the hydrated cations is observed ; probably, the cations become dehydrated under these conditions.

In the light of the above, it appears that the lack of agreement between the lime requirement, and the base binding capacities of soils obtained by the different routine methods arises from the fact that different types of cation effect are brought to bear in the different methods depending on the experimental conditions of each as a result of which different amounts of acid are displaced or neutralized even at a given *p*H, e.g. *p*H 7·0.

In the present paper, a comparative study has been made of the total acidities of colloidal solutions of hydrogen clays calculated from their electrometric titration curves as previously obtained in this laboratory* and their base binding capacities obtained by some recognized methods which do not depend on the titration principle. Such comparisons are expected to bring out (1) the significance of the total acidity values calculated from the titration curves in relation to the base binding capacities obtained by the routine methods and (2) the role of cation effects in determining the base binding capacities by such routine methods. The following methods have been used for the comparison :

1. Parker's method [Parker, 1929].
2. Mattson's method [Mattson, 1932].
3. Hissink's back titration method [Hissink, 1925].

It is intended in subsequent papers of this series to extend the work to hydrogen clays obtained from Indian soils other than those used in this work and to compare a larger number of routine methods. It is also intended to extend these studies to soils themselves and to bring the results on hydrogen clays and soils in mutual relation when sufficient experimental material will have accumulated.

*Systematic studies of these curves have been undertaken in a separate series of papers entitled ' On the nature of the reactions responsible for soil acidity '. See, in particular, Part V of this series (R. P. Mitra, this journal, Vol. 6, p. 555, 1936). Parts VI and VII have also been communicated for publication.

Experimental

1. Preparation of colloidal solutions of hydrogen clays

The hydrogen clays were prepared in the manner described in a previous paper [Mitra, 1936] from the clay fractions of the following two Indian soils (surface soils). The clay fractions were separated from the soils using the International soda method.

(*i*) Soil from Government Seed Farm, Kalyanpore (U. P.) ; a brown loam.

(*ii*) A black cotton soil from Satara Dt., Bombay Presidency ; calcium-saturated, neutral soil.

Hydrogen clay sols H and I respectively were obtained from the above soils.*

2. Methods of estimating total acidities and base binding capacities

(*a*) *Electrometric titration with bases in presence and absence of neutral salts*

The technique followed was as described in a previous paper [Mitra 1936]. Both hydrogen and glass electrodes were used.

(*b*) *Parker's method*

A known amount of the hydrogen clay was leached with a neutral normal solution of barium acetate. The adsorbed barium estimated as barium sulphate after displacing it by leaching the clay (which was now a barium clay) with a neutral normal solution of ammonium chloride gave the base binding capacity. The adsorbed Ba checked satisfactorily with the adsorbed NH_4.

(*c*) *Mattson's method*

To a series of jena glass bottles each containing a definite volume of the hydrogen clay sol was added a neutral salt sufficient to give an approximately normal solution. Increasing amounts of the corresponding base were added to the different bottles. The *p*H values of the mixtures were then determined using the glass electrode and a titration curve obtained by plotting these *p*H values against the equilibrium concentrations of the base added. To a second series of bottles containing only the salt solution in the concentration as previously used were also added increasing amounts of the base and on plotting the *p*H values against the final concentrations of the added base a second curve was obtained. The base binding capacity of the hydrogen clay at any *p*H was given by the distance (reckoned at this *p*H) between the two curves parallel to the axis showing the amounts of the base added.

(*d*) *Hissink's back titration method*

To a given volume of the hydrogen clay sol was added a sufficient amount of the base to make the resulting *p*H about 11·00. The amount of the base reacting with the hydrogen clay was obtained by conductometrically titrating the excess base with a standard acid. Different bases were used.

Results

The base binding capacities are given in Tables I and II.

*The first soil was obtained through the courtesy of the Superintendent, Government Seed Farm, Cawnpore. The other soil was kindly supplied by the Agricultural Chemist, Bombay.

TABLE I

Base binding capacity of hydrogen clay H obtained by different methods

Method.	Base binding capacity at *p*H 7·0 in m. e. base per 100 gm. colloid.
A. Electrometric titration in presence and absence of salts.	
Titration with—	
(i) $Ba(OH)_2$	32·0
(ii) $Ca(OH)_2$	32·8
(iii) NaOH	10·7
(iv) $Ba(OH)_2$ in presence of $BaCl_2$ (0·83)*N*	48·0
(v) $Ca(OH)_2$ in presence of $CaCl_2$ (0·83*N*)	47·0
(vi) NaOH in presence of NaCl (0·83*N*)	40·0
(vii) $Ba(OH)_2$ in presence of $Ba(Ac)_2$ (0·83*N*)	51·0
B. Mattson's method using—	
(i) $Ba(OH)_2$ and $BaCl_2$ (0·83*N*)	47·0
(ii) NaOH and NaCl (0·83*N*)	39·5
C. Parker's method	51·0
D. Hissink's method* using—	
(i) NaOH to give *p*H 11·1	80·2
(ii) $Ba(OH)_2$ to give *p*H 10·87	85·4
(iii) $Ca(OH)_2$ to give *p*H 10·90	88·2

TABLE II

Base binding capacity of hydrogen clay I obtained by different methods

Method	Base binding capacity at *p*H 7·0
A. Electrometric titration in presence and absence of salts—	
Titration with—	
(i) $Ba(OH)_2$	82·0
(ii) $Ca(OH)_2$	97·0
(iii) NaOH	78·0
(iv) $Ba(OH)_2$ in presence of *N* $BaCl_2$	110·5
(v) $Ca(OH)_2$ in presence of *N* $CaCl_2$	106·0
B. Mattson's method using—	
(i) $Ba(OH)_2$ and *N* $BaCl_2$	109·5
(ii) $Ca(OH)_2$ and *N* $CaCl_2$	105·0
C. Parker's method	110·5

*The base binding capacity estimated by this method does not correspond to *p*H 7·0. It really conforms to the *p*H finally attained on adding the alkali to the sol.

The results clearly bring out the variability of the total neutralizable acid as previously discussed. The manner of variations is also as previously indicated. Approximate agreement, however, is found to exist between the base binding capacities (at *p*H 7·0) obtained by methods A (iv), A (vii), B(i) and C. The agreement between A (iv) and B (i) is expected as B (i) (Mattson's method using Ba $(OH)_2$ in presence of $BaCl_2$) really amounts to a titration of the sol + salt mixture as carried out in A (iv) with the difference that in B (i) the titration is not continuous. B (i) also requires much larger quantities of the hydrogen clays than A (iv). The cation effects brought to bear in A (iv) and B (i) are the same and consequently, the same amount of acid is neutralized at a given *p*H, viz., *p*H 7·0.

The agreement with Parker's method (method C) which does not depend on the titration principle is interesting as it gives a definite significance to the total acidity values obtained on titrating the sol in the presence of barium chloride [A (iv)] and barium acetate [A (vii)]. An explanation of this agreement may be given in the light of the theoretical considerations already brought forward. When barium chloride or barium acetate is added to the colloidal solution of the hydrogen clay, the H^+ ions present in the double layers are exchanged for Ba^{++} ions. This interchange, however, being a reversible process, all the H^+ ions are not exchanged and at equilibrium, the relative distribution of Ba^{++} and H^+ ions in the double layer is determined by the distribution of these ions in the bulk of the liquid phase. The addition of baryta removes some H^+ ions from the liquid phase whose Ba^{++} /H^+ ratio thus increases. A new equilibrium between the solid and the liquid phases is, therefore, set up which requires a higher Ba^{++} /H^+ ratio in the double layer than what previously obtained. This latter ratio increases as the *p*H of the system rises, there being a definite relation between the absolute values of the ratios in the bulk of the liquid phase and in the double layer. Thus the amount of Ba absorbed, or, conversely, the amount of H^+ ions displaced from the double layer and neutralized is, as already explained, a function of the *p*H, the Ba^{++} ion concentration in the liquid phase remaining practically constant (*N*). At a different Ba^{++} ion concentration, the amount of acid neutralized at the same *p*H would be different. The smaller total acids of the sols measured at *p*H 7·0 obtained on titration with baryta alone than in the presence of barium chloride would be thus explained.

When the sol is leached with a solution of barium acetate as in Parker's method, the Ba^{++} ions of the leaching solution displace H^+ ions from the double layers ; these H^+ ions mostly form undissociated acetic acid molecules and are removed from the sphere of action as fast as they are displaced by the Ba^{++} ions. The colloidal practicles thus always find themselves in a medium having *p*H 7·0 and a normal Ba^{++} ion concentration. The conditions obtaining after the leaching has sufficiently progressed are identical with those reached on titrating the sol + $BaCl_2$ (*N*) mixture to *p*H 7·0 in so far as the Ba^{++}/H^+ ratio in the liquid phase is concerned. Under these conditions, the amount of Ba adsorbed from the barium acetate solution becomes, for reasons stated above, identical with the total acidity of the sol + $BaCl_2$ (*N*) mixture.*

*The slightly smaller total acid of the sol H + $BaCl_2$ mixture compared to the base binding capacity by Parker's method is probably due to the mixture containing 0·83*N* $BaCl_2$ instead of *N* $BaCl_2$.

Tables I and II show that Hissink's back titration method yields the highest base binding capacities. The results obtained with different bases are different increasing in the order : NaOH $<$ Ba $(OH)_2$ $<$ $Ca(OH)_2$. The high values obtained by this method are expected as in the highly alkaline regions obtaining under the conditions of the experiment more H^+ ions associated with the colloidal particles enter into the reaction with the base than would be the case in the neutral, or, acid region. The method is, however, open to the objection that a decomposition of the exchange complex may take place under the conditions of titration [Schofield, 1931]. A 'break down' of the absorption complex of a hydrogen clay from a lateritic soil from Bengal has been observed in this laboratory at *p*H 12·5. A second criticism against Hissink's method is that it measures the soil hydrogen under conditions of alkalinity which do not usually obtain in soil under field conditions.

Summary

The total acidities of colloidal solutions of hydrogen clays calculated from their electrimetric titration curves have been compared with their base binding capacities obtained by other methods. The total acid calculated at *p*H 7·0 from the titration curves is a variable quantity depending on the nature of the base used and on whether the titration is carried out in the presence or absence of a neutral salt using a given base. Titration of the sol+salt mixture yields a much higher total acid (expressed as m. e. base per 100 gm. colloid) than titration of the sol alone. Titration with baryta in presence of *N*-barium chloride, or, *N*-barium acetate yields the highest total acid and it is equal to the base binding capacity of the hydrogen clay obtained by Parker's method. Much higher values of the base binding capacity are obtained by the back titration method of Hissink. The results have been discussed in the light of cation effects which are brought to bear in the different methods of estimation.

REFERENCES

Clark, N. A. and Collins, E. R. (1930). *Soil Sci.* **29**, 417
Crowther, E. N. and Martin, W. S. (1925). *J. Agric. Sci.* **15**, 237
Daikuhara, G. (1914). *Bull. Jap. Imp. Centr. Agric. Expt. Sta.* **2**, 1
Gedroiz, K. K. (1924). *J. Expt. Agron.* **22**, 3.
————, (1929). *Der adsorbierende Bodenkomplex.*
Goy, S., Müller, P. and Roos, O. (1929), *Zeitschr. Pflanz. Düng., u. Bod.* **13A**, 66
Hardy, F., and Lewis, A. H. (1929). *J. Agric. Sci.* **19**, 17
Hissink, D. J. (1925). *Trans. Far. Soc.* **20**, 551
———— (1935). *Trans. 3rd Internatl. Cong. Soil Sci.* **2**, 68.
Hopkins, C. G. (1903). *U. S. Dept. Agric. Bur. Chem. Bull.* **73**
Joseph, A. F. and Oakley, H. B. (1925). *J. Chem. Soc.* **127**, 2813
Mitra, R. P. (1936). *Ind. J. Agric. Sci.* **6**, 555.
Mukherjee, J. N. (1922). *Phil. Mag.* **44**, 321.
Mukherjee, J .N.; Mitra, R .P. and Mukherjee, S. (1937). *Trans. Nat. Inst. Sci. Ind.* **1**, 227
Parker, F. W. (1929). *J. Amer. Soc. Agron.* **21**, 1030
Schofield, R. K. (1931). *Ann. Rep. Chem. Soc.* (London) **28**, 351
Way, J. T. (1852). *J. Roy. Agric. Soc.* **13**, 123.
Wiegner, G. (1925). *Koll. Zeitsch. Erg.-Bd.* **36**, 341

STUDIES ON SOIL TEMPERATURES IN RELATION TO OTHER FACTORS CONTROLLING THE DISPOSAL OF SOLAR RADIATION*

BY

R. K. DRAVID, M.Sc.,

Karnatak College, Dharwar, formerly Research Student, Agricultural Meteorology Section, Meteorological Office, Poona

(Received for publication on 8 May 1939)

(With five text-figures)

Introduction

IN December 1933 the present writer undertook, at the suggestion of Dr L. A. Ramdas, certain investigations on soil temperatures at the Central Agricultural Meteorological Observatory at Poona. These were intended to form part of a scheme of related investigations on the disposal of the radiation received from the sun and the sunlit sky. Apart from routine observations of soil temperatures a number of experiments were performed, mostly during the clear seasons of the last three years, in order to ascertain how far one can modify the thermal conditions in the soil layers near the surface of the ground. A brief account of the results was published in two recent notes [Ramdas and Dravid, 1934, 1936]. A fuller discussion of these results is attempted in the present paper.

A brief description of the city of Poona and its surroundings and of the general climate of the locality may serve as a useful introduction.

Description of Poona and its surroundings

Poona (Lat. 18° 30′ N., Long. 73° 53′ E.) is situated at the confluence of the two rivers, Mutha and Mula, near the western margin of the Deccan plateau at a height of 1,830 ft. above the mean sea level. The city is surrounded by numerous low hills.

The general features of the climate of Poona are brought out by Table I which gives the normals of the various meteorological elements for Poona.

The South-west monsoon sets in in June and continues up to the middle of September. The monsoon season is characterised by over-cast skies, frequent drizzling, high south-westerly or westerly winds and small diurnal variation of temperature. There are also occasional thundershowers in this part of India during the pre-monsoon and post-monsoon months.

The climate during the dry season with which we are concerned mainly in the present paper (November-April) is of the ' dry continental type ' essentially controlled by insolation during day and radiative cooling during night.

* This investigation was carried out while the present writer was working as a research student in the Agricultural Meteorology Section (financed by the Imperial Council of Agricultural Research) at the Meteorological Office, Poona. The paper is a revised form of the thesis submitted to the University of Bombay for the M.Sc. degree.

TABLE I *

Month	Mean daily Maximum (°F.)	Mean daily minimum (°F.)	Range (°F.)	Extreme maximum (°F.)	Extreme minimum (°F.)	Relative humidity (per cent)	Vapour pressure in inches of Hg.	Cloud in tenths of sky covered	Rain in inches	Number of rainy days	Wind (in miles per hour)	Direction
January	86·1	54·2	31·9	94·6	42·5	61	·330	1·3	0·06	0·2	4·5	N58W
February	90·6	56·2	34·4	101·9	38·8	54	·320	0·9	0·06	0·1	5·0	N84W
March	97·1	62·8	34·3	109·1	44·8	46	·349	1·0	0·06	0·2	6·1	N86W
April	101·1	68·9	32·2	109·6	50·5	43	·421	1·4	0·57	1·3	7·6	N82W
May	99·7	71·9	27·8	110·0	57·3	56	·567	2·2	1·20	1·8	10·6	N87W
June	89·6	72·6	17·0	106·5	63·0	73	·701	6·5	4·77	7·6	11·2	S87W
July	82·8	71·0	11·8	96·0	66·3	82	·711	8·6	7·01	12·3	11·6	S80W
August	81·7	69·6	12·1	92·1	62·9	84	·696	7·6	3·66	9·0	10·2	S84W
September	84·6	68·6	16·0	96·0	60·9	82	·684	6·4	4·84	7·5	7·9	W
October	89·1	66·5	22·6	100·0	52·3	73	·612	3·6	3·74	5·2	4·8	N61W
November	86·8	59·4	27·4	96·5	43·0	63	·444	1·9	0·98	1·7	4·5	N23E
December	84·7	53·9	30·8	95·0	42·5	61	·344	1·5	0·16	0·5	4·3	N40E

* Based on data recorded at Yeravda (Poona) from 1878-1920.

Clear skies, feeble air movements, large diurnal range of temperature and of relative humidity and low water vapour content of the air layers near the ground are the characteristics of this season. The Bombay-Deccan, of which Poona is fully representative, is more or less outside the areas directly affected by the north-east monsoon and the western disturbances during the winter months. The clear season extending over six months of the year in the Bombay-Deccan is, therefore, convenient for investigations on soil temperatures under comparatively simple climatic conditions.

Thermal balance at the soil surface

The variation of temperature with depth and time in the soil depends upon a number of factors which control the disposal of solar radiation at the earth's surface. These factors are enumerated below :—

1. The duration and intensity of the total radiation from the sun and the sunlit sky received by unit area of a horizontal surface.
2. The colour of the soil surface which determines what fraction of the incident energy is absorbed by the soil surface.
3. The thermal conductivity of the soil which depends upon :—
   (*a*) the chemical composition of the soil,
   (*b*) the water content, and
   (*c*) the pore space or apparent density.
4. The heat transfer from the heated soil surface by convective processes in the air layers near the ground.
5. The radiative exchange in the long wave-length or infra-red region of the spectrum between the soil surface and the atmosphere.
6. Evaporation and condensation of water vapour at the ground surface [Ramdas and Katti, 1934 ; 1936] ; during the clear season at Poona, the day to day variations in the moisture content of the surface soil are small compared to the diurnal variations, the loss by evaporation during the day being recouped more or less by absorption of water vapour from the atmosphere during night.

To determine the heat balance at the earth's surface it is necessary to make a systematic measurement of each of the above factors. The Central Agricultural Meteorological Observatory at Poona, which was started in 1933, has been slowly improving the equipment necessary for a complete scheme of observations

1. Intensity of radiation from the sun and the sunlit sky and the duration of hours of clear sunshine

The measurement of total radiation from the sun (S) and sky (H) is made at the Central Agricultural Meteorological Observatory by using a Moll Solarigraph which consists of a sensitive thermopile and a recording Millivoltmeter (made by Messrs Kipp and Zonen-Delft). The monthly means of the total daily radiation expressed in gramme-calories, the number of days for which records were available and the mean duration of sunshine as recorded by a Campbell-Stokes Sunshine recorder are given in Table II

TABLE II

Mean daily values of S + H (i.e. energy received from the sun and sky) expressed in gramme-calories per sq. cm., duration of sunshine, etc., during different months of the year 1935.

	January	February	March	April	May	June	July	August	September	October	November	December
Mean daily value of S+H	511	644	725	784	775	565	388	439	526	474	600	473
Number of days of observations	31	28	31	30	31	30	11	5	22	23	8	21
Mean daily hrs. of sunshine	8·5	10·4	10·6	11·2	10·9	7·2	3·1	3·7	5·9	7·3	9·5	8·7
Maximum value of S+H	606	715	794	846	855	817	643	507	690	656	622	575
Minimum value of S+H	274	450	661	691	602	131	116	325	302	261	555	318
Mean of S+H on clear days	558	659	734	799	798	759	...	...	691	627	600	515
Number of clear days	14	24	23	19	20	5	...	...	1	5	8	10
Mean of S+H on overcast days	375	...	...	...	...	380	319	325	360	261	...	372
Number of overcast days	4	...	...	...	...	3	5	1	3	1	...	4

for the different months of the year 1935 [Raman, 1935]. In the same table the highest and the lowest values of S+H, recorded during each month, are also given. For the sake of comparison the mean values of S + H on clear days alone and on over-cast days are given separately along with the number of occasions of each type at the bottom of the table.

The mean values of S + H on clear days alone during different months give an idea of the intensity of possible radiation in different seasons. April and May are seen to be the two months in which the possible radiation income is greatest and December shows the minimum possible radiation. No records of clear days are available for the months of July and August, but there is no doubt that the intensity of possible radiation in these months would be intermediate between those of June and September.

2. Albedo of the surface of the ground

It is necessary to see what fraction of the incoming solar energy is actually absorbed and converted into heat by the soil surface for a study of the heat economy at the earth's surface. For this purpose it is sufficient to measure the reflection co-efficient or the albedo of the surface for the visible radiation which preponderates in the solar spectrum. These reflection coefficients were determined by using a Moll thermopile with a glass window and a cone and a sensitive galvanometer. The thermopile was directed towards the sunlit surface under experiment and then towards a standard white surface of French chalk also exposed to full sunshine. The deflection in the first case when divided by the deflection in the second case gives the albedo, if we assume that the chalk surface diffuses all the incident radiation. Measurements were made for the surfaces mentioned in Table III.

TABLE III

Kind of surface	Albedo (per cent)
French chalk	100 (assumed)
Charcoal powder	6
Poona black cotton soil	16
Grass covered soil	32
Sakrand soil	41
Belgaum soil	15
Quartz powder	72

It is interesting to note that the surface of Poona soil absorbs 84 per cent of the incident radiation. In fact, soil temperatures of the order of 75°C are occasionally recorded at Poona during the summer. Other soils

referred to in the Table III are typical Indian soils which are not so absorbing as the black cotton soil of the Deccan.

3. Thermal diffusivity of the soil

We shall refer in detail later on to the seasonal variation of the thermal diffusivity of the black cotton soil at Poona. It would, however, be appropriate to refer here to the seasonal variation of soil moisture in the different layers of the soil as this is the most important factor which is responsible for the variations in the thermal diffusivity under field conditions. Weekly determinations of soil moisture at depths of 0, 2 in., 4 in., 6 in., 8 in., 12 in. and 18 in. were made from the middle of July 1935, on the bare plot of the Central Agricultural Meteorological Observatory. The data up to the end of November 1936, i.e. over a period of about sixteen months, are shown in Fig. 1 which gives the isopleths of soil moisture. This diagram illustrates the variation of moisture both with depth and with time. The isopleths are drawn at intervals of 5 per cent (moisture content of soil expressed as percentages of dry weight of soil). From the daily rainfall indicated by the length of the vertical lines in the upper portion of the diagram it will be seen that the spells of rain cause the high moisture content lines to approach the surface and that, during the frequent breaks in the monsoon rains at Poona, the moisture content fluctuates rapidly in the first six inches of the soil. After the withdrawal of the monsoon the surface layers of the soil are subjected to more or less unbroken desiccation during the long spell of dry weather extending from the first week of November 1935 to the beginning of June 1936. It is interesting to note that after the initial desiccation the isopleths remain nearly horizontal during the dry season with the 5 per cent line near the surface and the 25 per cent line at a depth of about 1 foot. The diagram brings out quite strikingly the protecting influence of the dry surface soil on the layers below of which the moisture content never goes below 25 per cent.

The fact that the lower layers of the black cotton soil at Poona have a comparatively steady value of moisture content is due to its high water-holding capacity which sets a limit also to the depth down to which percolation can occur with the light rainfall over this tract.

4. Convective heat transfer from the ground surface

Some of the thermal energy which accumulates at the surface during the day time is partly conducted into the lower layers of the soil and partly transmitted to the air layers near the ground by convection. (We shall refer to the heat transfer by radiative processes in the next section). The heat transfer from the ground by convection takes place mostly during day time when the surface is warmer than the air above it. Raman [1936] working at Poona has made a simple apparatus for measuring directly the heat carried away from unit area of the ground surface in unit time. A full account of his method will be found in the paper referred to. Fig. 2 curve (C) shows the hourly values of the heat loss by convection in gramme calories per minute on a clear day (23-4-1936). The curve rises quickly after sunrise attaining a maximum between 14 and 15 hours. Later the value decreases rapidly and becomes negligible after sunset.

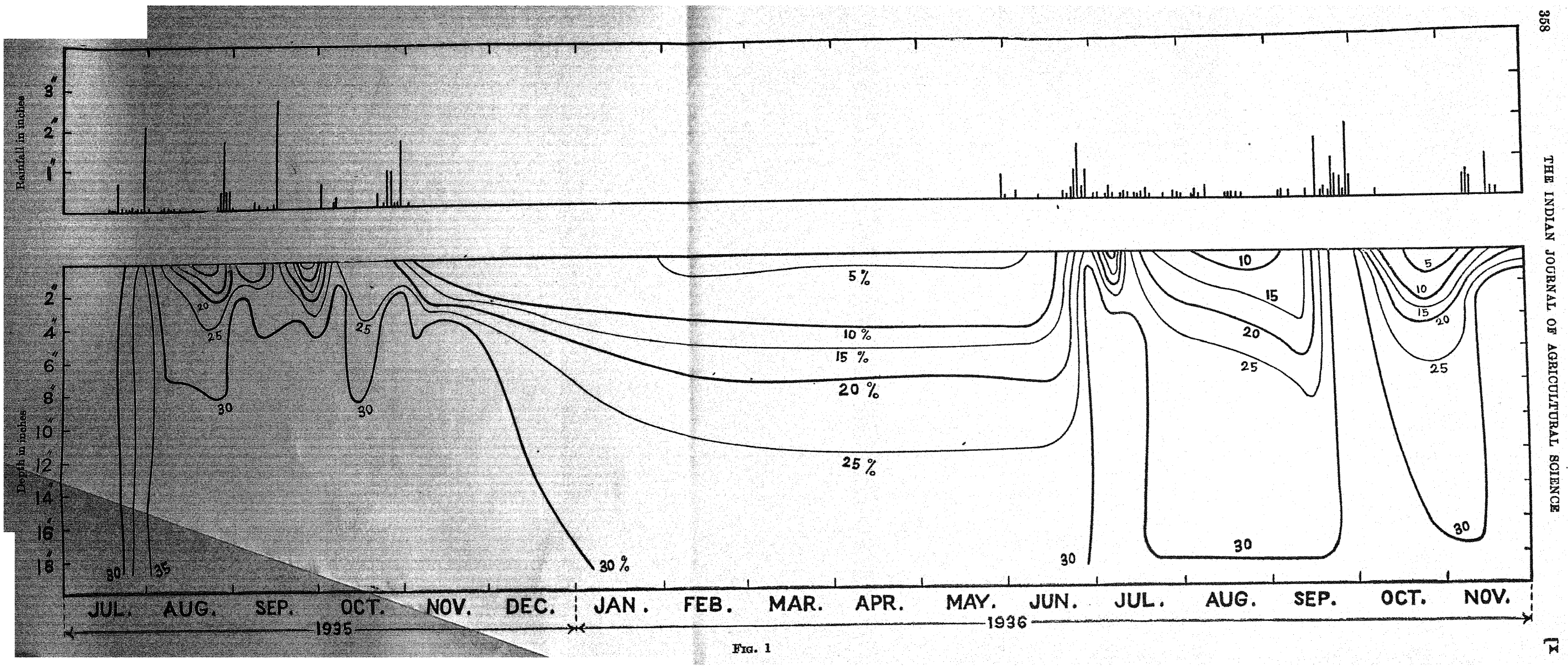

Rainfall in inches
1"
2"
3"
Depth in inches
2"
4"
6"
8"
10"
12"
14"
16"
18"
5 %
10 %
15 %
20 %
25 %
30 %
30
35
25
20
10
15
5
JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY. JUN. JUL. AUG. SEP. OCT. NOV.
1935
1936

FIG. 1

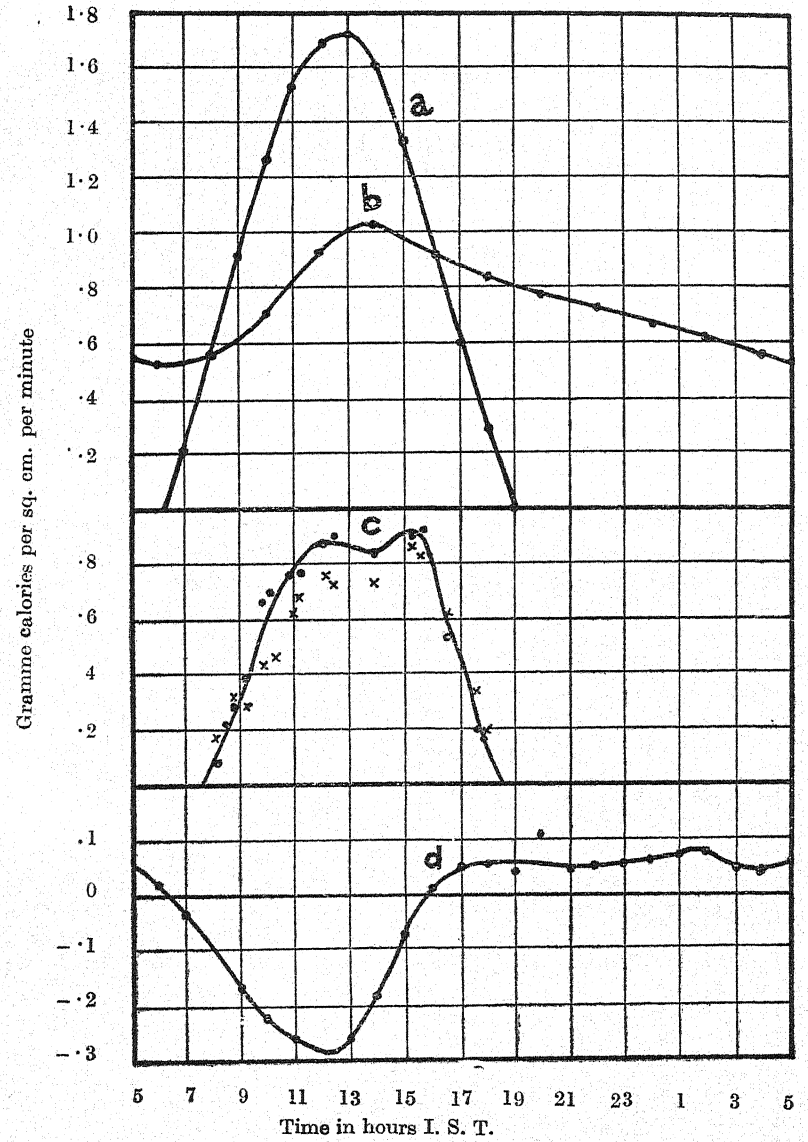


FIG. 2. (23-4-36) (*a*) Radiation from sun (S) and sunlit sky (H); (*b*) Temperature radiation going out from the ground surface; (*c*) Heat loss by convection from the ground surface; (*d*) Heat transfer by conduction between soil surface and the soil layers below.

5. *Radiative exchange in the long-wave-length or infra-red region of the spectrum between the soil surface and the atmosphere*

Earth radiation.—During the day time the soil surface is receiving solar radiation in the visible region of the spectrum a part of which it absorbs and converts into thermal energy. The diurnal wave of the surface temperature very closely follows the altitude of the sun and the intensity of the

radiation arriving at the surface from the sun and the sunlit sky. After sunset the surface of the ground begins to cool and the cooling continues until sunrise on the next morning. Bodies at the temperature of the earth's surface emit long wave or heat radiation. The energy radiated has its maximum value at about 10μ, and most of the radiation is confined to the wave-length interval 3μ to 50 μ. In this region of the spectrum the surface of the ground emits and absorbs like a black body so that, knowing the surface temperatures T^s (from surface thermograph records or actual hourly observations of surface temperature) we can calculate the total energy E radiated to a hemisphere by unit area of a horizontal surface per second from the relation $E = \sigma T_s^4$ gramme calories per second, where σ is equal to $1 \cdot 37 \times 10^{-12}$ and T_s is the surface temperature in degrees absolute. If the atmosphere contained no water vapour all the heat energy radiated by the surface would be lost to space ; the atmosphere, however, always contains sufficient water vapour to absorb and re-radiate some of this energy back to the surface of the ground. The heat radiation $\bar{S}$ coming from the night sky as a whole towards unit area of the surface of the ground per minute is measured by means of Angstrom's pyrgeometer. Table IV below gives the mean values of air temperature in degrees absolute, the vapour pressure in mm. of Hg, the black body radiation and $\bar{S}$ the sky radiation, in gramme calories per sq. cm. per minute on clear (cloudless) nights alone during the months of 1934 (excepting July, August and September).

TABLE IV

Mean monthly values of radiation $\bar{S}$ from the night sky, etc., on clear days in 1934

Month	Number of observations	Air temperature degrees absolute	Vapour pressure in mm. of Hg	σT^4 gm. cal/ cm.^{2} minimum	$\bar{S}$ gm. cal/ cm^2. minimum
January	7	287	4·7	·556	·386
February	28	295	7·0	·622	·444
March	26	299	9·4	·645	·477
April	22	301	12·5	·671	·490
May	27	302	13·9	·684	·497
June	5	301	17·1	·669	·505
October	3	294	11·3	·607	·463
November	23	290	9·6	·577	·437
December	19	288	7·0	·563	·436

6. The heat exchange by conduction between the soil surface and the layers soil below

During day time, when the temperature θ_o at the surface is higher than θ_1 at unit depth below the surface, the thermal current will flow downwards from the surface. At night when θ_o becomes lower than θ_1, the thermal current will flow upwards towards the surface. In general, on a calm and clear day, the heat conveyed downwards and upwards respectively will be roughly of the same order of magnitude, but during transition months when there is an upward or downward trend in the annual variation of temperature there will be some positive or negative carry over to the next day. If θ_o and θ_1 are the mean temperatures during an hour, the heat conducted into a lower layer through the 1st unit layer with a mean temperature θ_m would be $\lambda(\theta_0-\theta_1)$ per unit time per sq. cm. and if the unit layer is itself changing in temperature at the rate $\frac{d\theta_m}{dt}$ the accumulation of heat in the unit layer itself will be $C.\frac{d\theta_m}{dt}$ per unit time per sq. cm. where C is the specific heat of the soil. It will be clear, therefore, that the amount of heat conducted from a surface of the soil will be given by $\lambda(\theta_o-\theta_1)+C.\frac{d\theta_m}{dt}$. Using the appropriate signs for $\theta_0-\theta_1$, and $\frac{d\theta_m}{dt}$, and knowing the values of θ_o, θ_1 and θ_m from curves showing the hourly variation of these temperatures it is possible to compute the amount of heat leaving or arriving at unit area of the soil surface per unit time or during hourly intervals.

We are now in a position to consider the thermal balance at the soil surface. We shall consider the conditions on the 23rd April 1936, a clear day during the summer at Poona. Fig. 2, curve (*a*) gives the march of solar+sky radiation (S + H) arriving at the surface. The albedo of the surface for visible radiation may be taken as 15 per cent. The mean value of $\bar{S}$, the heat radiation from the atmosphere, was ·480 gm. cals./cm²/mt. Curve (*b*) in the same diagram shows the hourly variation of σT^4 or the heat radiation emitted by the soil surface. Curve (*c*) shows the hourly variation of the heat transferred from the soil surface by convection. Curve (*d*) shows the heat loss by conduction into the soil layers. In this curve, the portion above the zero-line indicates the gain of heat at the surface by conduction during the night from the lower layers of the soil and the portion below the zero-line indicates the heat lost by conduction into the lower layers from the soil surface during the day hours. The values of the different factors are expressed in Fig. 2 in gramme calories per sq. cm. per minute.

THE SCHEME OF EXPERIMENTS ON SOIL TEMPERATURES

Having discussed the various factors which control the disposal of solar energy at the earth's surface, we may now go on to the subject of soil temperature and its variation with different soils and with different conditions at the surface.

In a note [Ramdas and Dravid, 1934] published in *Current Science* a simple scheme for conducting experiments on soil temperatures has been outlined. As mentioned in the previous section the temperatures attained by different layers of a soil, when its surface is exposed to solar radiation and to the other contemporary meteorological phenomena, will depend to a large extent upon the colour and cover of the surface and the chemical and physical composition of the different layers below the surface.

Johnson and Davies [1927] have measured temperatures at a depth of one centimetre in blocks of tar, macadam, bare earth, sand, rubble, and bare clay 1 metre square and 15 cm. deep. In view of the fact that the samples were 15 cm. deep their results represent the joint effects of the colour and composition of the materials used.

For a preliminary and a comparative study of the behaviour of different typical soils with respect to soil temperatures, the variation due to climatic differences from place to place was eliminated by bringing sufficiently large amounts of the selected soils to one place of observation, viz. the Central Agricultural Meteorological Observatory at Poona.

The experiments were made in distinct stages as follows :—

1. The physical and chemical properties of the soil were kept identical by working with plots of the undisturbed local soil ; the plots measured $6\frac{1}{2}$ ft. by $3\frac{1}{2}$ ft. each and similar sets of thermometers were installed at the different depths.

The type of the thermometer used (manufactured by R. Fuess) has a bend near the bulb which makes it easy to fix the bulb at a definite depth, the whole length of the mercury in the bulb lying horizontally at the depth at which the temperature has to be measured. It is also convenient to take the temperature readings from the scale attached to the outer tube surrounding the slender stem, as the stem is inclined to the vertical away from the observer. The thermometer reads correct to one-tenth of a degree Centigrade. The soil thermometers were all compared with a standard thermometer before installation. Corrections, if any, were applied to the recorded observations.

After installing the thermometers at the required depths, comparative observations were taken to verify that the temperatures at corresponding depths were similar. One of the plots (A plot) was kept as a permanent ' control ' plot and each of the remaining plots covered with thin layers of substances like chalk, charcoal powder and typical soils from different parts of India. The simultaneous observations were then continued in order to record the influence of the ' cover ' on the temperatures of the soil layers below.

Along with these experiments it was also arranged to measure the effects of surface wetting and of a cover of vegetation on the soil temperatures.

2. Having ascertained the effect of cover, the effect of varying both the physical and chemical composition of the soil was studied by using blocks of different soils measuring $6\frac{1}{2}$ ft. in length, $3\frac{1}{2}$ ft. in breadth and 1 ft. in depth. The soil blocks were kept with their natural surfaces exposed in the first part of the experiment and, after comparative observations had proceeded for a sufficiently long time, all except the local ' control ' plot were covered with

a thin layer of the local black cotton soil so as to eliminate the influence of the surface colour and retain only the variations due to the interior of the blocks of different soils.

Experiments on the effect of soil cover

The experiments carried out in order to study the effect of various soil covers are taken up for discussion in the order in which they were carried out.

Experiment 1: Effect of a thin cover of French chalk on soil temperatures

The soil thermometers were installed in the standard plot A and in the experimental plot B, at depths of 0 cm., 5 cm., 10 cm., 15 cm., 20 cm. and 30 cm.

Two hourly observations were taken of the temperatures shown by the two sets of thermometers at the different depths, after the conditions in the soil layers in the two plots had become normal. It was thus ascertained that the temperatures of the different layers of the soil in the two plots were similar. After the observations had been continued for a sufficient number of days, the plot B was covered with a thin layer (about 1 mm.) of French chalk powder (white in colour) uniformly all over the surface, so that there was no patch of the local black cotton soil left bare and exposed to the sun. The plot A was left untreated and used as a permanent 'control' plot.

The two hourly observations were continued as before. The white surface of the B plot reflected most of the solar radiation and absorbed very little solar radiation whereas the black surface of the standard A plot absorbed about 85 per cent of the energy which would be diffused by the white surface of chalk. Naturally, the temperatures at the different depths in the B plot were considerably lowered as compared to the corresponding temperatures of the A plot. Of course, these changes of temperature took place immediately at the surface but reached their full values only after two days at 10 cm. depth, and four days at 50 cm. depth.

For a convenient discussion of these data, the observations were grouped in weeks according to the scheme given by Sir Napier Shaw, in his paper *The Book of the Grower's year*.

Table V gives the weekly average temperatures of the A and B plots at the depths of 0, 5, 10, 15, 20 and 30 cm. and at the times 0600 hrs., 0800 hrs., 1000 hrs., 1400 hrs., 1600 hrs. and 1800 hrs.

During week No. 1 (25th to 31st of December 1933), both the A and B plots were in their natural untreated condition. It can be seen that the temperatures at different depths are very similar in both the plots at the different epochs during this week. At 1700 hrs. on the 31st of December 1933, plot B was covered with a very thin layer of French chalk powder. The lowering effect in the temperature of plot B was observed during the next three weeks when the chalk cover was retained, viz.—

Week No. 2, January 1 to January 7, 1934,

Week No. 3, January 8 to January 14, and

Week No. 4, January 15 to January 20.

TABLE V

Effect of a thin cover of chalk powder on soil temperatures in °C. (Plot A: Control plot; Plot B: Experimental plot to which the cover of chalk powder was applied at 1700 hrs. on 31st December 1933; the cover was removed at 1700 hrs. on 20th January 1934)

Depth	No. of week	0600 hrs.		0800 hrs.		1000 hrs.		1400 hrs.		1600 hrs.		1800 hrs.	
		A	B	A	B	A	B	A	B	A	B	A	B
0 cm.	1	11·0	11·2	17·3	17·4	30·4	30·3	44·9	44·9	34·4	33·8	25·6	25·5
	2	14·7	14·3	19·5	16·8	30·5	23·3	42·1	31·3	35·3	28·1	27·2	23·8
	3	12·1	10·9	17·6	13·7	33·5	21·9	50·1	31·9	41·9	29·3	28·9	23·4
	4	9·8	8·4	14·8	12·2	32·2	23·9	50·6	36·7	41·9	32·1	29·3	24·1
	5	11·9	11·6	16·4	16·9	33·2	33·4	49·6	48·8	42·0	40·9	28·6	27·6
	6	12·7	12·6	18·4	18·5	31·5	31·0	46·5	45·3	42·2	41·4	28·6	28·3
5 cm.	1	17·3	17·1	16·9	16·7	24·6	24·6	30·1	30·3	29·1	29·3	28·1	28·1
	2	19·5	18·1	19·0	17·5	22·7	20·3	28·7	24·0	28·8	24·4	27·1	23·6
	3	18·9	16·4	18·3	15·9	22·0	18·2	31·3	24·1	31·7	24·7	29·3	23·7
	4	17·2	14·7	16·5	14·1	20·7	16·6	31·1	23·7	31·9	24·6	29·5	23·3
	5	18·0	17·3	17·7	16·9	20·3	19·7	31·8	31·3	31·9	31·1	28·8	27·7
	6	19·2	18·7	18·7	18·4	22·1	22·2	31·7	31·9	31·9	32·1	29·6	29·1
10 cm.	1	20·6	20·3	19·6	19·3	23·0	22·9	24·9	24·9	26·1	26·0	28·0	28·0
	2	21·7	20·1	20·9	19·3	21·9	20·4	24·8	21·8	26·5	23·1	26·5	23·3
	3	21·8	19·3	20·8	18·4	21·3	18·6	26·1	21·4	28·2	22·9	28·3	23·1
	4	20·5	17·5	19·5	16·8	19·8	16·8	24·9	20·1	27·2	22·0	27·4	22·1
	5	21·0	20·1	20·3	19·2	18·9	17·8	25·0	24·6	26·6	26·3	26·2	25·8
	6	22·2	21·9	21·2	20·9	21·6	21·3	26·1	26·1	27·1	27·1	27·5	27·4
15 cm.	1	22·6	22·5	21·8	21·7	23·7	23·7	23·0	22·9	25·9	25·9	26·5	26·5
	2	23·1	21·7	22·5	21·1	22·7	21·5	23·3	21·5	24·7	22·4	25·3	22·8
	3	23·6	21·0	22·9	20·5	22·6	20·3	24·0	20·9	25·7	21·9	26·4	22·4
	4	22·5	19·6	21·7	19·1	21·3	18·7	22·7	19·5	24·5	20·7	25·2	21·1
	5	22·4	21·9	22·0	21·3	20·3	19·4	23·0	22·3	24·1	23·5	24·2	23·7
	6	23·9	23·7	23·1	22·9	23·0	22·8	24·2	24·1	24·8	24·9	25·6	25·8
20 cm.	1	23·6	23·4	23·1	22·9	24·4	24·3	22·8	22·9	24·5	24·8	24·9	25·4
	2	23·7	22·4	23·4	22·0	23·5	22·4	23·1	21·9	23·6	22·4	24·1	22·7
	3	24·3	22·0	23·0	21·6	23·8	21·4	23·7	21·4	24·2	21·8	24·6	22·1
	4	23·4	20·6	22·9	20·2	22·6	19·9	22·5	20·0	23·1	20·6	23·5	20·9
	5	23·2	22·6	22·9	22·1	21·7	20·6	22·6	22·0	22·8	22·5	22·5	22·5
	6	24·5	24·5	24·1	23·8	24·1	23·9	23·8	23·9	23·8	24·1	24·2	24·8
30 cm.	1	24·4	24·4	24·3	24·2	25·2	25·1	24·1	23·9	24·8	24·7	24·9	24·8
	2	24·3	23·2	24·2	23·2	24·3	23·3	24·1	23·1	24·1	23·0	24·2	23·0
	3	25·0	23·0	24·9	23·0	24·9	23·0	24·7	22·8	24·5	22·7	24·5	22·7
	4	24·1	21·8	23·9	21·7	23·9	21·7	23·7	21·6	23·6	21·5	23·6	21·4
	5	23·7	23·2	23·7	23·1	23·5	22·2	23·4	22·7	23·3	22·5	22·7	22·0
	6	25·0	25·0	24·8	24·8	25·1	25·0	24·5	24·5	24·3	24·3	24·3	24·3

The differences in temperatures are relatively small in the morning but in the afternoon they show up very conspicuously. Thus the effect of the French chalk cover is to lower the temperatures at 6 a.m. by 1·2°C, 2·5°C, 2·5°C, 2·6°C, 2·3°C and 2·0°C at depths of 0, 5, 10, 15, 20 and 30 cms. respectively. The temperatures of the covered plot are lowered by 18·2°C, 7·2°C, 4·7°C, 3·1°C, 2·3°C and 1·9°C respectively at 2 p.m. These lowerings in temperatures have been noted from the average temperatures during week No. 3, i.e. January 8 to 14, 1934, the second week after the cover of French chalk was applied. Similarly the lowerings in the temperatures at the various depths due to the white chalk cover may be noted at the different times of observation.

Figs. 3 (*a*) and 3 (*b*) are isopleths of the weekly mean temperatures at 1400 hrs. (afternoon) in the control and chalk-covered plots respectively. The abscissae refer to the successive weeks and the ordinates refer to the depths below surface. The plots were similar during the first week. The very conspicuous lowering of the soil temperatures during the second, third and fourth weeks in the chalk covered plot is shown by the rapid approach of the isotherms towards the surface.

The chalk powder was removed from the surface of the B plot at 1700 hrs. on the 20th January 1934 after having remained for three successive weeks. It is interesting to note the gradual return of the isotherms in the treated plot to their normal values. It took more than a week after the removal of the chalk for the temperatures to equalize in the two plots. During the first week after the removal of the cover (January 21 to 28) the temperatures are still seen to be differing in value. But, in the next week (January 29 to February 1) the temperatures are again more or less similar in the two plots.

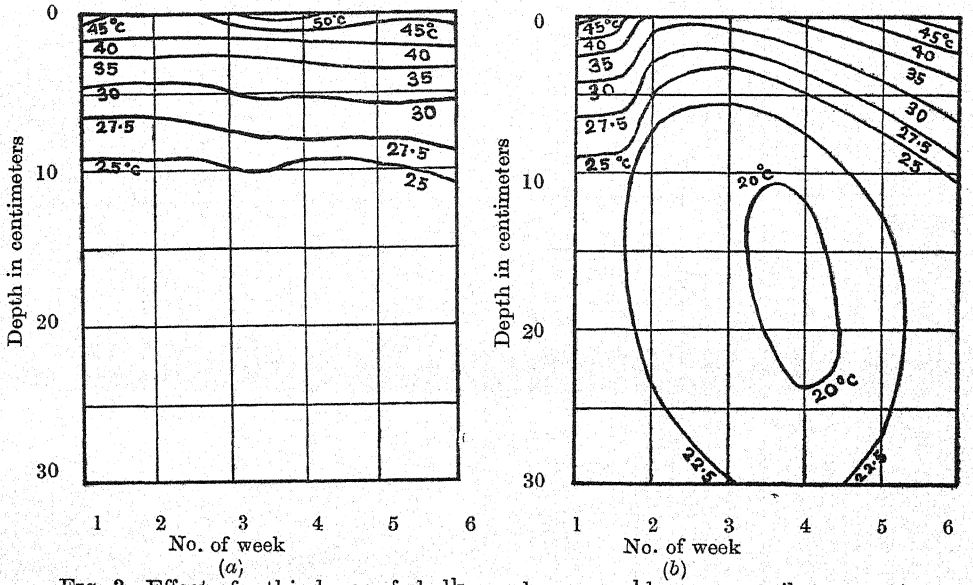


FIG. 3. Effect of a thin layer of chalk powder on weekly mean soil temperatures at 1400 hrs. I. S. T. (25-12-33 to 1-2-34). (*a*) Control; (*b*) Chalk put on at the beginning of the 2nd week. Chalk removed at 1700 hrs. of 20-1-34 (end of 4th week).

Experiment 2: Effect of a thin cover of charcoal powder on soil temperatures

After the conditions in the B plot had become normal and the temperatures in both the plots had become similar, a thin cover of charcoal powder was laid on the surface of the B plot uniformly at sunset (1818 hrs.) on the 1st of February, 1934.

Table VI gives the weekly average temperatures at the maximum and minimum epochs, i.e. 0600 hrs. and 1400 hrs. at the various depths in the two plots. The dates corresponding to the different periods are as follows :—

No. of period	Dates
1	29-1-34 to 1-2-34
2	2-2-34 to 11-2-34
3	12-2-34 to 18-2-34
4	19-2-34 to 25-2-34
5*	5-3-34 to 11-3-34
6	12-3-34 to 18-3-34
7	19-3-34 to 25-3-34

* Observations were not recorded during the period 26th February to 4th March 1934.

Evidently, the black charcoal cover should absorb more solar radiation and consequently raise the temperatures in B plot. Since, however, the local Poona soil is also black, there is not much difference in the 'albedo' or colour effect of the soil and the cover (charcoal powder) used. Naturally, such large differences of temperature as were obtained in the first experiment with chalk cover cannot be expected in this experiment. All the same, a distinct rise in temperatures in plot B can be noticed.

TABLE VI

Effect of a thin cover of charcoal powder on soil temperatures in °C (Plot A : Control plot; Plot B : Experimental plot to which the cover of charcoal powder was applied at 1818 hrs. sunset, on 1st February 1934; the cover was removed at 1700 hrs. on 18th March 1934)

No. of week	Depth	0600 hrs.		1400 hrs.	
		A	B	A	B
1	0 cm.	12·7	12·6	46·5	45·3
2		11·9	12·4	53·8	54·7
3		14·1	14·5	55·7	57·4
4		12·3	12·9	56·0	57·9
5		13·6	14·1	56·6	59·1
6		14·5	15·1	57·1	59·0
7		19·6	19·5	58·4	58·3
1	5 cm.	19·2	18·7	31·7	31·9
2		18·9	18·9	35·3	36·3
3		21·2	21·4	38·2	39·5
4		20·5	20·6	37·7	39·5
5		20·9	21·5	38·5	41·2
6		21·6	22·2	38·7	41·4
7		25·6	25·4	42·3	42·6

TABLE VI—*contd.*

No. of week	Depth	0600 hrs. A	0600 hrs. B	1400 hrs. A	1400 hrs. B
1	10 cm.	22·2	21·9	26·1	26·1
2		22·3	22·6	27·3	27·6
3		24·5	25·0	30·4	30·5
4		24·5	25·1	30·2	30·4
5		25·0	25·7	31·5	31·7
6		25·5	26·4	31·8	32·1
7		28·2	28·6	34·8	34·5
1	15 cm.	23·9	23·7	24·2	24·1
2		24·1	24·4	24·7	25·2
3		26·2	26·7	27·1	27·8
4		26·6	27·0	27·2	27·9
5		27·1	27·7	27·7	28·7
6		27·5	28·3	28·4	29·3
7		29·8	29·9	30·8	31·2
1	20 cm.	24·5	24·5	23·8	23·9
2		24·7	25·0	24·0	24·6
3		26·6	27·2	26·0	27·0
4		27·1	27·7	26·5	27·3
5		27·6	28·3	27·1	28·0
6		28·1	28·9	27·6	28·6
7		29·9	30·3	29·6	30·3
1	30 cm.	25·0	25·0	24·5	24·5
2		25·0	25·4	24·7	25·1
3		26·7	27·3	26·4	27·0
4		27·5	28·1	27·2	27·8
5		27·9	28·7	27·7	28·3
6		28·4	29·1	28·2	28·8
7		30·0	30·3	29·8	30·0

Thus, the effect of the cover of charcoal powder is to raise the temperatures in plot B at 6 a.m. by 0·5°C, 0·6°C, 0·7°C, 0·6°C,0·7°C and 0·8°C and at 2 p.m. by 2·5°C, 2·7°C, 0·2°C, 1·0°C, 0·9°C and 0·6°C respectively at the depths of 0, 5, 10, 15, 20 and 30 cm. These differences are taken from the average temperatures during the week March 5 to 11, 1934, i.e. the fifth period after the charcoal cover was applied. The cover was carefully removed at 1700 hrs. on the 18th of March 1934. The average temperatures during

the week after the removal of the cover are also given in Table VI against period No. 7. These are more or less similar.

Experiment 3 : Effect of wetting the soil surface with water equivalent in amount to 1/4 in. of rain

After the temperatures in plots A and B had attained normal values plot B was wetted with $\frac{1}{4}$ in. rain equivalent of water sprinkled uniformly all over the surface at sunrise (0625 hrs.) on the 14th of April 1934.

Table VII gives the observations recorded. After two observations at 0600 and 0625 hrs., the plot was watered ; and then up to 8 a.m. observations were taken at intervals of 15 or 20 minutes ; from 8 am. to 10 a.m. half-hourly observations were taken and then at 1400, 1500, 1600, 1700 and 1800 hrs. on the 14th of April. From the 15th to 20th April the observations were recorded only at 0600, 0800, 1000, 1400, 1600 and 1800 hrs.

The general effect of the watering is to lower the temperatures in the B plot considerably.

At the surface, we can clearly see how the temperature of the control plot goes on rising after sunrise at the usual rapid rate, while that of the watered plot lags more and more. Whereas at 0640 hrs. the surface temperature of plot B (21·5°C) is slightly higher than that of plot A (21·1°C), at 0700 hrs. the temperature of A (22·4°C) is higher than that of B (21·2°C). At 1000 hrs., we find the surface temperature of control plot (A) higher by 15·8°C and at 1400 hrs. by 14·6°C than the corresponding temperature of the watered plot (B). At 1600 hrs., in the evening, the difference is only 5·8°C. The slower rate of rise and fall of temperatures in plot B is partly due to the increase of the specific heat of the soil due to the presence of water and partly due to the heat utilized for the evaporation which is taking place at the wet surface.

On the 15th April, at the maximum temperature epoch, the surface temperature of plot B is 3·2°C lower than that of plot A, while on the 20th April the difference is only 0·8°C which is almost negligible. Thus after about a week, the lowering effect produced in the surface temperature of the plot B by watering, equivalent to $\frac{1}{4}$ in. of rain, is no longer significant.

The maximum difference between the temperature at 2 cm. depth in the two plots is noticed at 1400 hrs., viz. 11·7°C on the day of watering. On the next day at the same hour, the difference is 5·5°C while on the 20th April it is only 1·5°C.

At the depth of 5 cm. the difference in the temperatures of the two plots is 4·8°C at 1400 hrs. and 5·0°C at 1500 hrs. and 1600 hrs. on the date of wetting. On the next day, the difference at 1400 hrs. is 3·0°C.

The lowerings in the temperatures at 2 p.m. at the depths of 10 cm., 15 cm., and 20 cm. in plot B are 2·6°C, 1·0°C and 0·0°C on the 14th April and 2·5°C, 1·4°C and 0·4°C on the 15th April. Up to 6 p.m. on the day of watering the temperature at the depth of 20 cm. has not been in the least affected in the B plot, but at 6 a.m. the next day we see a fall of 1°C in the temperature. We thus observe that the effect of cooling travels very slowly ; it takes more than 12 hrs. to reach a depth of 20 cm.

TABLE VII

Effect of wetting the surface of the soil on soil temperatures in °C. (Plot A : Control plot ; Plot B : Experimental plot of which the surface was wetted with a quantity of water equivalent to $\frac{1}{4}$ in. rain at 0625 hrs. sunrise on 14th April 1934)

Date	Time	0 cm.		2 cm.		5 cm.		10 cm.		15 cm.		20 cm.	
		A	B	A	B	A	B	A	B	A	B	A	B
14th April 1934	0600	19·2	19·8	22·5	23·5	26·2	26·5	30·0	30·6	32·2	32·4	32·9	33·0
	0625	19·8	20·4	23·0	23·8	26·2	26·5	29·8	30·4	32·0	32·2	32·8	33·0
	0640	21·0	21·5	23·2	24·6	26·2	26·4	29·7	30·2	32·0	32·2	32·8	32·8
	0700	22·4	21·2	24·0	24·8	26·2	26·5	29·6	30·2	31·9	32·1	32·8	32·8
	0715	24·5	22·2	25·0	25·0	26·5	26·8	29·5	30·0	31·8	32·0	32·8	32·7
	0730	26·4	23·3	26·4	25·5	26·9	27·1	29·5	30·0	31·8	32·0	32·8	32·6
	0745	27·6	23·3	27·5	25·7	27·6	27·4	29·5	30·0	31·7	31·8	32·7	32·6
	0800	29·6	23·3	28·5	25·8	28·3	27·7	29·5	30·0	31·6	31·8	32·6	32·5
	0830	33·5	25·6	30·4	26·5	29·5	28·0	29·8	30·0	31·6	31·7	32·6	32·5
	0900	40·0	29·2	34·2	28·5	31·0	28·8	30·3	30·1	31·5	31·6	32·5	32·4
	0930	44·8	32·2	38·0	31·0	32·4	30·0	30·6	30·3	31·5	31·6	32·5	32·4
	1000	49·0	33·2	40·8	32·8	34·3	31·3	31·2	30·4	31·6	31·6	32·4	32·3
	1400	68·8	54·2	56·0	44·3	46·1	41·3	37·4	34·8	33·8	32·8	32·5	32·5
	1500	67·0	54·1	56·3	45·0	47·4	42·4	39·0	36·1	34·8	33·5	32·8	32·8
	1600	61·9	52·2	55·0	44·9	47·6	42·6	39·9	36·9	35·4	34·0	33·1	33·1
	1700	53·0	46·0	49·5	41·9	46·2	41·5	40·2	37·2	36·0	34·4	33·4	33·4
	1800	42·9	37·1	45·5	38·0	43·6	38·8	39·8	37·0	36·6	34·8	33·8	33·8
15th April 1934	0600	20·0	18·8	24·2	24·0	28·0	26·8	31·0	30·0	32·6	31·6	33·2	32·2
	0800	30·0	28·8	29·2	27·0	28·6	27·2	30·3	29·5	32·2	31·2	33·0	32·0
	1000	52·1	49·6	42·8	38·5	37·0	34·6	32·4	31·0	32·1	31·2	32·8	31·7
	1400	64·0	60·8	55·5	50·0	46·8	43·8	39·0	36·5	34·8	33·4	33·0	32·6
	1600	59·6	56·6	52·3	47·5	46·0	43·2	39·8	37·4	35·6	34·1	33·4	33·0
	1800	40·7	38·8	42·8	38·3	42·1	39·3	39·7	37·3	36·8	35·3	34·0	33·6

TABLE VII—*contd.*

Date	Time	0 cm.		2 cm.		5 cm.		10 cm.		15 cm.		20 cm.	
		A	B	A	B	A	B	A	B	A	B	A	B
16th April 1934 . . .	0600	22·2	21·6	26·0	26·0	29·4	28·8	32·4	31·2	33·6	32·4	33·6	32·8
	0800	29·2	28·8	29·0	28·0	29·4	28·6	31·6	30·8	33·0	32·0	33·2	32·6
	1000	46·5	44·8	40·0	37·0	35·2	33·7	32·4	31·3	32·8	31·9	33·2	32·4
	1400	68·4	64·8	56·2	51·0	46·8	44·2	38·8	36·7	34·8	33·8	33·2	33·0
	1700	47·6	46·5	47·8	44·8	44·8	43·2	40·4	38·8	36·8	35·5	34·0	34·2
	1800	40·0	39·2	43·2	41·2	42·6	41·4	39·6	38·3	37·0	35·7	34·4	34·4
17th April 1934 . . .	0600	22·7	22·3	27·0	27·0	30·1	29·2	32·6	31·6	33·6	32·8	33·7	33·0
	0800	29·2	29·0	29·0	28·0	29·8	28·8	31·6	31·0	32·9	32·2	33·4	32·8
	1000	46·4	45·0	40·0	37·1	35·6	34·0	32·4	31·5	32·7	32·1	33·4	32·6
	1400	64·8	62·8	52·5	49·5	44·6	43·2	38·4	36·4	34·8	33·8	33·2	33·2
	1600	55·8	54·3	49·2	47·0	43·3	43·3	39·8	38·2	36·0	34·9	33·8	33·8
	1800	41·3	39·8	42·8	41·2	41·5	41·0	39·0	38·0	36·6	35·4	34·2	34·4
18th April 1934 . . .	0600	21·6	21·8	25·4	25·9	28·4	28·4	31·4	31·1	33·2	32·6	33·6	33·2
	0800	30·4	30·0	29·0	28·6	29·0	28·5	30·8	30·2	32·5	31·8	33·2	32·6
	1000	47·0	46·0	39·0	36·5	34·5	33·4	32·4	31·4	32·4	31·8	33·0	32·4
	1400	60·2	58·0	51·0	47·0	43·8	42·0	37·4	36·0	34·2	33·4	33·0	33·0
	1600	51·3	49·6	47·7	44·5	43·0	42·2	38·8	37·8	35·4	34·5	33·6	33·6
	1800	37·0	35·1	41·3	38·8	40·7	40·0	38·0	37·5	36·0	35·0	34·0	34·2
19th April 1934 . . .	0600	18·6	18·9	23·2	24·0	27·0	27·3	30·6	30·2	32·5	31·9	33·2	32·6
	0800	35·8	34·8	31·5	30·0	29·2	28·7	29·8	29·4	31·6	31·0	32·6	32·0
	1000	49·6	48·0	39·7	37·0	34·1	33·0	31·3	30·5	31·6	31·1	32·5	31·8
	1400	61·2	59·2	51·2	48·0	43·3	42·2	37·0	35·7	33·6	32·2	32·4	32·4
	1600	52·2	50·8	46·3	43·7	42·3	41·1	38·6	37·4	35·2	34·3	33·1	33·3
	1800	39·5	37·9	40·1	38·2	40·0	38·9	37·8	37·0	35·7	34·9	33·5	33·8
20th April 1934 . . .	0600	21·2	21·6	24·8	25·2	27·6	28·0	30·8	30·8	32·6	32·0	33·0	32·6
	0800	26·2	26·4	27·0	27·5	27·6	27·5	30·0	30·2	32·0	31·6	33·0	32·2
	1000	46·9	45·4	37·8	35·8	33·6	32·8	31·3	30·6	31·7	31·3	32·5	31·9
	1400	56·8	56·0	47·0	45·5	41·2	42·0	37·4	36·8	34·5	33·8	32·8	33·0
	1600	51·8	51·5	45·0	44·3	40·8	41·6	38·1	37·3	35·1	34·2	33·1	33·4
	1800	39·6	38·2	40·4	39·3	39·5	39·2	37·9	37·1	35·7	34·7	33·5	33·9

Experiment 4: Effect of wetting the surface of the soil with water equivalent in amount to $\frac{1}{2}$ in. of rain

After the soil temperatures in the two plots A (control) and B (experimental) had become more or less similar for a number of days the surface of the plot B was wetted uniformly with water equivalent to $\frac{1}{2}$ in. of rain. From Table VIII it will be seen that the effect of wetting plot B on the morning of the 3rd May (6 a.m.) has been to depress the afternoon soil temperatures in that plot by 11·1°C, 14·8°C, 10·7°C, 4·4°C, 3·1°C, 2·0°C, 0·4°C and 0·2°C at depths of 0, 0·5, 2, 5, 10, 15, 20 and 30 cm. respectively. The recovery from the effect of wetting is perceptible even on the next day; but it is only after the 6th May that the temperatures in the two plots become more or less equal.

TABLE VIII

Soil temperatures in °C in two plots A (control) and B (experimental) during the period 3rd to 6th May, 1934, showing the effect of wetting the surface of the plot B on the morning of 3rd May 1934

Morning 6 a.m.

Dates	3-5-34		4-5-34		5-5-34		6-5-34	
Depth cm.	A	B	A	B	A	B	A	B
0	22·8	23·8	21·3	20·2	19·2	18·5	16·6	17·1
0·5	24·0	24·7	22·4	20·6	20·5	19·6	18·5	18·0
2	27·0	27·0	25·2	23·0	24·0	23·0	22·0	21·5
5	29·1	29·4	28·0	25·9	27·3	26·0	25·8	25·2
10	31·6	32·0	30·4	28·7	30·6	29·8	29·6	29·5
15	33·2	33·2	32·7	30·2	32·5	31·3	32·1	31·0
20	33·6	33·8	33·6	32·0	33·4	32·0	33·1	32·1
30	33·8	33·8	33·9	32·9	33·8	32·8	33·6	32·6

Afternoon 2 p.m.

Dates	3-5-34		4-5-34		5-5-34		6-5-34	
	A	B	A	B	A	B	A	B
0	66·4	55·3	63·3	59·8	62·1	60·0	64·5	63·5
0·5	61·0	46·2	57·8	53·4	56·5	54·1	59·8	57·8
2	50·8	40·1	48·0	42·1	46·4	43·3	49·2	46·5
5	41·6	37·2	39·8	36·1	37·8	37·5	39·8	39·6
10	36·9	33·8	36·0	33·3	35·3	33·2	35·6	33·6
15	34·4	32·4	33·8	31·7	33·5	31·6	33·0	31·5
20	33·3	32·9	33·2	32·0	33·0	32·2	32·4	31·9
30	33·5	33·3	33·6	32·6	33·4	32·5	33·1	32·4

Figs. 4 (*a*) and 4 (*b*) are the isopleths of daily temperatures at 1400 hrs. in the control and surface-wetted plots respectively. The wetting was done at 6 a.m. on the third day. The sudden cooling communicated to the various soil layers is shown by the rapid approach of the isotherms towards the surface on the third day. The recovery from the effects of wetting was gradual and the temperatures had not yet equalized even on the 6th day.

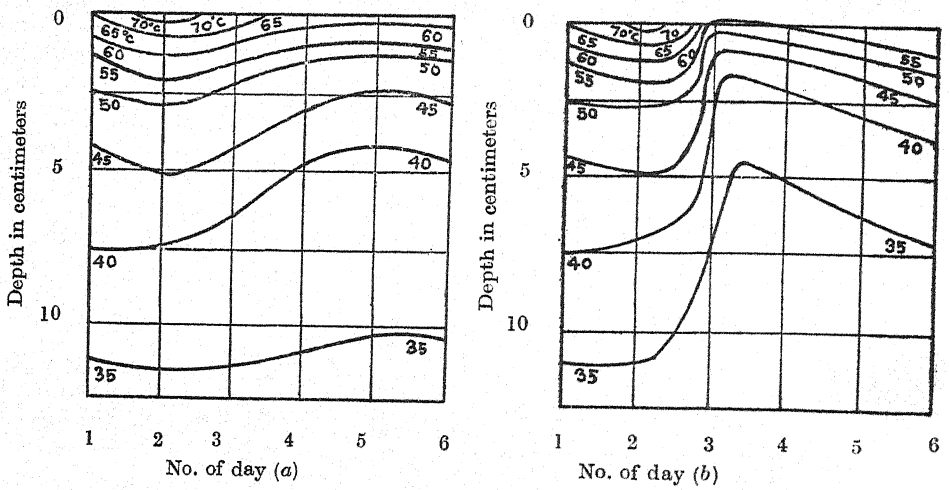


FIG. 4. Effect of watering the surface on daily soil temperature at 1400 hrs. I. S. T. (1-5-34 to 6-5-34). (*a*) Control ; (*b*) Surface moistened on 3-5-34.

Experiment 5 : Effect of a cover of vegetation on soil temperatures

After making a survey of the effects of changing the surface cover on soil temperatures as outlined in the preceding paragraphs, an attempt was made to study the effect of a cover of vegetation on the temperatures of the soil. The three plots A, B and C were used for this experiment. Plot A was used as 'control'. After comparative observations under similarc onditions had been made for some days, plot C was sown with 'aleev' on September, 4th, 1935. Plot B was kept bare but received periodical watering to the same extent as plot C. The height of the 'aleev' crop was 24 cm. on the 11th of October, 28 cm. on the 19th of October, and 30 cm. on 4th of November. It was trimmed to 20 cm. on 17th of November. Table IX shows the weekly average temperatures at 0600 hrs. and 1400 hrs. at depths of 0, 2, 5, 10, 15 and 20 cm. for the following weeks :—

Week No.	Dates
1	22nd to 28th August 1935
2	20th to 26th November 1935
3	27th November to 3rd December 1935

TABLE IX

Morning and afternoon average soil temperatures during three weeks in the three plots A, B, C, at different depths showing the effect of a plant cover on the plot C, the plot B being given the same amount of water as the plot C and the plot A being left untreated as the standard control plot. Week 1 before treatment; weeks 2 and 3 after treatment

Depth in cm.	No. of week	Morning 0600 hrs. Soil temperatures °C			Afternoon 1400 hrs. Soil temperatures °C		
		Control plot A	Plot receiving equal amount of watering as plot C B	Plant covered plot C	Control plot A	Plot receiving equal amount of watering as plot C B	Plant covered plot C
0 cm.	1	21·2	21·2	21·2	40·8	40·8	40·8
	2	9·1	8·8	10·6	54·3	37·8	27·8
	3	10·5	9·7	13·9	54·7	38·8	24·1
2 cm.	1	23·7	23·7	23·7	33·9	33·9	33·9
	2	16·2	12·3	14·9	37·3	28·7	26·7
	3	17·2	13·4	15·9	39·1	30·8	26·0
5 cm.	1	24·6	24·6	24·6	31·7	31·7	31·7
	2	16·9	13·8	15·5	32·8	24·9	24·1
	3	17·8	14·7	16·4	34·7	26·4	24·2
10 cm.	1	26·5	26·5	26·5	29·3	29·3	29·3
	2	21·3	18·3	19·0	25·8	21·4	20·3
	3	21·8	18·8	19·6	26·4	21·9	20·7
15 cm.	1	27·7	27·7	27·7	28·0	28·0	28·0
	2	23·6	20·9	20·5	23·7	20·6	20·1
	3	23·8	21·1	20·9	24·1	20·9	20·5
20 cm.	1	27·9	27·9	27·9	27·6	27·6	27·6
	2	24·3	21·9	21·1	23·8	21·0	20·7
	3	24·5	22·1	21·2	24·0	21·2	20·8

During the first week when all the plots were similar, the temperatures at all depths in the three plots were in agreement. The mean temperatures at the different depths during weeks No. 2 and No. 3 clearly bring out the effects of the watering alone in B and of watering and crop cover in C. In the morning, soil temperatures in plot C in the layers near the surface are warmer than in plots A or B. This is due to the blanketing effects of the vegetative cover which keeps even the air layers inside the vegetation warmer than those outside over bare ground. In the afternoon, however, plot C is cooler than plot A by as much as 26·5°C, 10·6°C, 8·7°C, 5·5°C, 3·6°C and 3·1°C at depths of 0, 2, 5, 10, 15 and 20 cm. The plot B is also cooler than plot A but is warmer than plot C in the afternoon. The conditions during week No. 3 are similar. The effect of a covering of vegetation in keeping down the temperatures during hours of insolation is well illustrated by these data.

Experiments with soil blocks

Experiment 1 : *Black cotton soil (control), Trivandrum sand and Sakrand soil blocks*

In the present section we shall deal with experiments with blocks of some typical soils. These experiments were started with soils from Trivandrum (sand), and Sakrand (alluvium). Pits $6\frac{1}{2}$ ft. by $3\frac{1}{2}$ ft. and 1 ft. deep were dug, keeping the bottom of the pits horizontal. The vertical sides of the pits were supported with a lining of brick and cemented up. The lining of cement helps to prevent the seepage of water from the sides during rainy weather. These pits were carefully packed with the soils referred to above, the top surfaces of the different soil blocks so obtained being kept horizontal and at the same level as that of the ground in the neighbourhood. The sets of soil thermometers were then installed in these soil blocks and compared with those in the permanent control plot. The natural surfaces of the respective soil blocks were kept undisturbed during the first part of the experiment which extended from the 30th of April to 10th of May, 1936. The second part of the experiment was commenced on the 11th of May at 0800 hrs. when the blocks of Trivandrum sand and Sakrand soil were covered with a thin layer (2 mm.) of black cotton soil so as to equalize the surface colours and retain only the variation in the interior of the soils. The observations recorded during the first and the second part of the experiment have been averaged for the following periods both for 6 a.m. and 2 p.m.

No. of period	Dates	Remarks
1	30 April to 6 May 1936	1st part of experiment with each soil block having its own colour
2	7 May to 10 May 1936	
3	11 May to 20 May 1936	2nd part of experiment with all soils having a cover of black cotton soil
4	21 May to 27 May 1936	
5	28 May to 3 June 1936	
6	4 June to 10 June 1936	

Table X gives the mean soil temperatures at different depths for the above 6 periods at 6 a.m. and 2 p.m. From the table it will be seen that during the first two periods before equalizing the covers the temperatures in the upper layers of Trivandrum sand are lower than those in the control both in the morning and evening. The surface temperature in the Sakrand soil is lower than that in the control but higher than that in the Trivandrum sand both in the morning and in the afternoon ; but below 10 cm. the temperatures are slightly warmer than in the other two soils. After equalizing the covers, i.e. during the periods 3 to 6 the temperatures in the sand and in the Sakrand soil begin to increase rapidly and approach those in the control. Sand being a poor conductor of heat, the afternoon temperature just below the surface is higher in it than in either the control or the Sakrand soil ; for the same reason the morning temperatures in the uppermost layers of the sand are lower than in the other two cases in spite of the colours having been equalized.

TABLE X

Morning and afternoon average soil temperatures in °C in three soil blocks of Poona soil (control), Trivandrum sand and Sakrand soil during six weeks. Weeks 1 and 2 show the temperatures in the blocks with their natural surface colours ; during weeks 3, 4, 5 and 6 a thin cover of Poona soil equalized all the surface colours

No. of week	0600 hours			1400 hours		
	Control A	Trivandrum sand D	Sakrand soil E	Control A	Trivandrum sand D	Sakrand soil E
			0 cm.			
1 . . .	21·9	17·9	20·3	69·7	58·1	63·8
2 . . .	21·7	19·1	21·1	68·1	58·0	64·5
Thin 'covers' of Poona soil were applied to plots E and D at 0800 hrs. (11-5-1936).						
3 . . .	23·3	20·3	23·2	68·9	68·1	66·6
4 . . .	24·9	22·1	24·6	63·5	64·3	62·8
5 . . .	22·9	20·5	22·9	51·8	51·5	50·9
6 . . .	21·5	19·3	21·7	48·4	45·8	45·7
			2 cm.			
1 . . .	26·7	24·1	24·4	54·9	53·8	55·8
2 . . .	28·5	24·7	25·3	52·1	52·5	54·9

TABLE X—*contd.*

No. of week	0600 hours			1400 hours		
	Control A	Trivandrum sand D	Sakrand soil E	Control A	Trivandrum sand D	Sakrand soil E
Thin 'covers' of Poona soil were applied to plots D and E at 0800 hrs. (11-5-1936)						
3 . . .	28·4	26·1	27·0	51·6	58·9	55·8
4 . . .	29·1	27·4	28·0	49·1	56·3	53·9
5 . . .	26·1	25·7	24·9	40·3	46·0	44·9
6 . . .	24·0	24·4	23·4	36·2	42·7	41·6
5 cm.						
1 . . .	27·5	26·6	27·3	48·6	45·8	48·8
2 . . .	28·5	27·1	28·0	47·8	45·8	48·5
Thin 'covers' of Poona soil were applied to plots D and E at 0800 hrs. (11-5-1936)						
3 . . .	28·9	28·8	29·5	46·3	50·0	49·2
4 . . .	29·5	29·3	30·0	44·1	49·0	47·8
5 . . .	26·1	27·3	26·9	37·0	40·5	39·7
6 . . .	24·1	26·1	25·3	32·6	38·2	37·3
10 cm.						
1 . . .	31·5	29·2	31·3	38·1	39·9	40·0
2 . . .	32·2	29·9	31·9	38·1	39·7	40·3
Thin 'covers' of Poona soil were applied to plots D and E at 0800 hrs. (11-5-1936)						
3 . . .	32·7	31·6	32·7	37·5	42·7	41·2
4 . . .	32·5	31·8	32·7	36·8	41·9	40·7
5 . . .	30·1	29·5	29·8	33·6	36·5	35·8
6 . . .	27·8	28·0	27·9	30·5	35·0	34·3
15 cm.						
1 . . .	33·3	31·6		34·0	35·1	
2 . . .	33·8	32·2		34·4	35·3	

TABLE X—*concld.*

No. of week	0600 hours			1400 hours		
	Control A	Trivandrum sand D	Sakrand soil E	Control A	Trivandrum sand D	Sakrand soil E
Thin ' covers ' of Poona soil were applied to plots D and E at 0800 hrs. (11-5-1936)						
3 . . .	34·0	34·0		34·4	37·7	
4 . . .	33·6	34·0		34·1	37·3	
5 . . .	31·9	31·5		32·0	34·0	
6 . . .	29·6	29·8		29·8	32·5	
20 cm.						
1 . . .	33·3	33·2	34·5	33·0	33·1	33·9
2 . . .	33·7	33·7	34·9	33·3	33·4	34·4
Thin ' covers ' of Poona soil were applied to plots D and E at 0800 hrs. (11-5-1936)						
3 . . .	33·8	35·3	35·8	33·4	35·1	35·2
4 . . .	33·3	35·3	35·5	33·0	35·1	35·1
5 . . .	32·1	33·0	33·2	31·8	33·0	32·9
6 . . .	29·9	31·0	31·1	29·7	31·4	31·2
30 cm.						
1 . . .	33·3	32·9	33·9	33·1	32·7	33·8
2 . . .	33·7	33·3	34·3	33·6	33·2	34·3
Thin ' covers ' of Poona soil were applied to plots D and E at 0800 hrs. (11-5-1936)						
3 . . .	33·8	34·5	35·1	33·6	34·2	34·9
4 . . .	33·3	34·5	35·0	33·2	34·3	34·7
5 . . .	32·3	33·6	33·6	32·1	33·3	33·3
6 . . .	30·1	32·0	31·9	30·1	31·7	31·6

Experiment 2 : Black cotton soil (control) and Bangalore (red) soil blocks

A similar experiment comparing the temperature in the control plot and in a block of red soil from Bangalore was started on the 9th of May 1936, as soon as a supply of the latter soil was received. The periods into which the 1st and 2nd parts of the experiment were divided were as follows :—

No. of period	Dates	Remarks
1	9 May to 15 May	1st part of experiment with each soil block having its own colour
2	16 to 22 May	
3	23 to 29 May	2nd part of experiment with Bangalore soil block having a cover of black cotton soil.
4	30 May to 5 June	
5	6 to 12 June	

Table XI gives the mean soil temperatures at different depths for the above 5 periods at 6 a.m. and 2 p.m. From the table it will be seen that during the first two periods before equalizing the covers the temperature at the surface of the Bangalore soil is lower than that of the control in the afternoon, but slightly greater than that of the control at lower depths. On applying the cover of the local soil at the beginning of the 3rd week, the afternoon surface temperature becomes more or less similar to that in the control but lower depths become still warmer owing to the larger absorption of energy at the surface and its conduction downwards. The changes of temperature on covering with local soil in the case of Bangalore soil are not of course so conspicuous as in the case of Trivandrum sand in the previous experiment. Further work on these lines is in progress at the observatory.

TABLE XI

Morning and afternoon average soil temperatures in °C in two soil blocks of Poona soil (control) and Bangalore soil during five weeks, weeks 1 and 2 show the temperatures in the blocks with their natural surface colours ; during weeks 3, 4 and 5 the surface colours are equalized in the blocks, a thin cover of Poona soil being applied to Bangalore soil block

Week No.	0600 hours		1400 hours	
	Control	Bangalore soil	Control	Bangalore soil
	0 cm.			
1	21·7	22·1	69·5	65·3
2	24·9	24·7	66·6	62·6

TABLE XI—*contd.*

Week No.	0600 hours		1400 hours	
	Control	Bangalore soil	Control	Bangalore soil
Thin cover of Poona soil was applied at 1800 hours on 22nd May 1936.				
3	24·8	25·1	59·7	60·1
4	22·2	22·6	45·8	45·4
5	21·3	21·9	53·5	52·0
5 cm.				
1	28·6	27·4	47·4	50·1
2	29·3	28·5	45·4	48·1
Thin cover of Poona soil was applied at 1800 hours on 22nd May 1936.				
3	29·3	28·8	42·5	47·5
4	24·7	24·9	33·7	36·4
5	24·7	25·4	34·4	40·5
10 cm.				
1	32·6	31·0	38·1	43·0
2	32·6	31·1	37·1	41·8
Thin cover of Poona soil was applied at 1800 hours on 22nd May 1936.				
3	32·2	31·6	36·4	41·5
4	28·9	27·5	31·7	35·0
5	28·1	27·7	31·2	37·8
15 cm.				
1	34·1	34·0	34·6	36·6
2	33·9	33·6	34·3	36·1
Thin cover of Poona soil was applied at 1800 hours on 22nd May 1936.				
3	33·5	34·0	33·7	35·9
4	30·9	30·3	31·0	32·4
5	29·8	30·2	30·1	33·4

Week No.	0600 hours		1400 hours	
	Control	Bangalore soil	Control	Bangalore soil
	20 cm.			
1	33·9	35·3	33·5	35·0
2	33·6	34·8	33·3	34·5
Thin cover of Poona soil was applied at 1800 hours on 22nd May 1936				
3	33·2	34·9	32·9	34·7
4	31·3	32·0	30·9	31·8
5	30·0	31·8	29·8	31·9
	30 cm.			
1	33·9	35·7	33·8	34·9
2	33·6	35·0	33·4	34·4
Thin cover of Poona soil was applied at 1800 hours on 22nd May 1936.				
3	33·3	35·1	33·1	34·5
4	31·6	32·9	31·4	32·4
5	30·1	32·4	30·0	32·0

Thermal diffusivity of the soil

The well-known equation of thermal conductivity in a continuous medium like the soil is given by

$$K.\frac{d^2\theta}{dx^2} = \rho c.\frac{d\theta}{dt}$$

where K is the thermal conductivity, θ is the temperature, x is the depth, ρ is the apparent density, c the specific heat and t the time.

The equation may be written more simply as

$$\frac{d\theta}{dt} = k.\frac{d^2\theta}{dx^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $k = \frac{K}{\rho c}$ = thermal diffusivity which is the change of temperature which would be produced in unit volume of the soil by the quantity of heat that flows in unit time through unit area of a layer of unit thickness having unit difference of temperature between its faces.

The solution of the above equation for the case where the temperature at the surface of the soil undergoes a diurnal variation, which may be for simplicity represented by a sine curve, is given by

$$\theta=\theta_0 e^{\frac{-2\pi x}{\lambda}} \cdot sin\, 2\pi \left(\frac{t}{T}-\frac{x}{\lambda}\right) \quad . \quad . \quad (2)$$

where T=time period of the wave, i.e., 24 hours aud λ=' wave-length ', i.e. distance between points at which the maxima or minima of temperature occur simultaneously. By substituting the above solution in (1) we can show that $k=\frac{\lambda^2}{4\pi T}$ so that

$$\frac{2\pi}{\lambda}=\sqrt{\frac{\pi}{T k}} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If we put θ_0=the amplitude of the diurnal variation at depth $x=0$, it is clear that the amplitude at a depth x is given by

$$\theta_0 e^{-\sqrt{\frac{\pi}{T k}} \cdot x}$$

Knowing the amplitudes of diurnal variation at two depths x_1 and x_2, we have from the above relation

$$\frac{\theta_1}{\theta_2}=e^{-(x_1-x_2)\sqrt{\frac{\pi}{T k}}} \quad . \quad . \quad . \quad (4)$$

Putting T=24 hours=86,400 seconds, and taking logarithms of the various quantities to the base 10, we have

$$\log k=2\left\{\log (x_1-x_2)-\log (\log \theta_1-\log \theta_2)\right\}-5\cdot1640 \; .. \; (5)$$

Knowing x_1, x_2 and θ_1 and θ_2 we can easily calculate k, the diffusivity of the soil at different intervals of depth.

Fig. 5 shows the diurnal variation of soil temperature on a clear day, viz. 0600 hrs. of the 30th April to 0600 hrs. of the 1st May 1935, at depths of 0, 2, 5, 10, 15 and 20 cms. below the surface. It will be noticed that besides the rapid decrease of the amplitude of the temperature wave with depth there is also a progressive lag in the epochs of maximum and minimum temperature. This is easily understood from equation (2). The maximum temperature at a depth x_1 is attained at time t_1, when $\sin 2\pi \left(\frac{t_1}{T}-\frac{x_1}{\lambda}\right)=1$

or where $2\pi \left(\frac{t_1}{T}-\frac{x_1}{\lambda}\right)=\left(2n+\frac{1}{2}\right)\pi$

Similarly the maximum epoch at a depth x_2 will be attained at time t_2, given by $2\pi \left(\frac{t_2}{T}-\frac{x_2}{\lambda}\right)=\left(2n+\frac{1}{2}\right)$

By subtraction we have

$$2\pi\left(\frac{t_2-t_1}{T}-\frac{x_2-x_1}{\lambda}\right)=0$$

so that

$$\frac{t_2-t_1}{x_2-x_1}=\frac{T}{\lambda}=\frac{T}{\sqrt{4\pi Tk}}=\sqrt{\frac{T}{4\pi k}}$$

We can thus find out k from the variation of the phase of the maximum or minimum temperature epochs, and put

$$k=\frac{T}{4\pi}\cdot\frac{(x_2-x_1)^2}{(t_2-t_1)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

or $\log k=3\cdot8373+2\log(x_2-x_1)-2\log(t_2-t_1)$ .....(7), the logarithms being taken to the base 10.

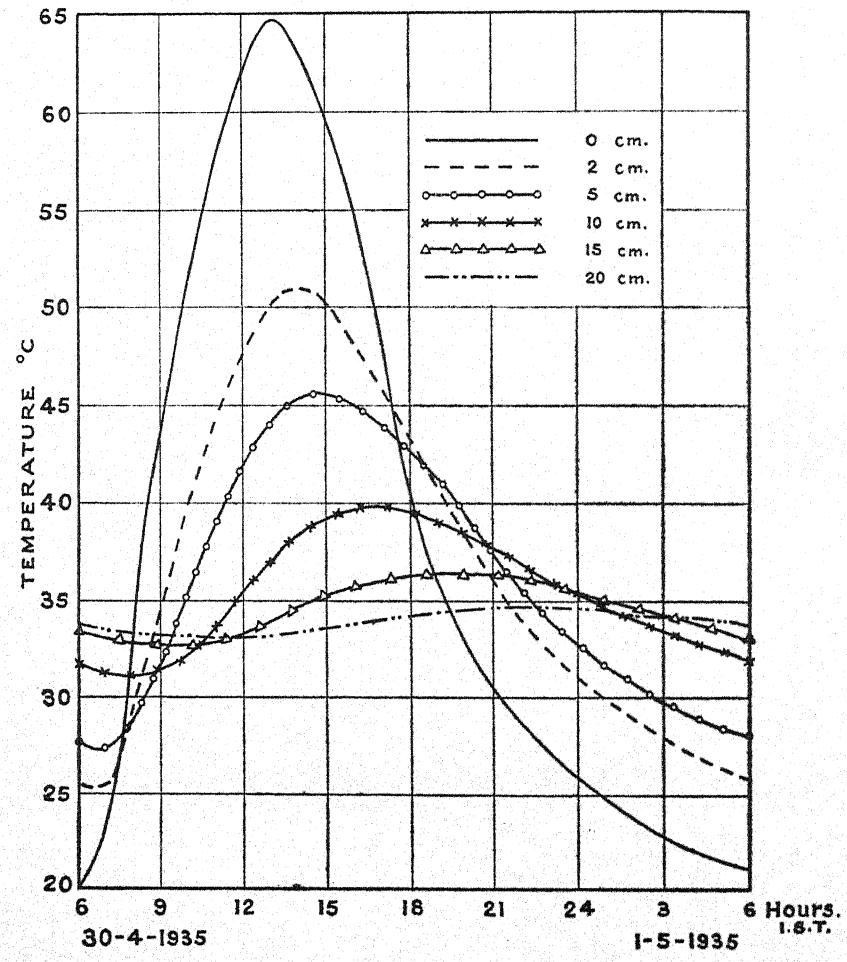


FIG. 5. Diurnal variation of soil temperature at 0, 2, 5, 10, 15 and 20 cm. depths from 0600 hrs. of 30-4-1935 to 0600 hrs. of 1-5-1935

For calculating k from the temperature curves, it is more convenient to use equation (5) as the amplitudes of the curves are much easier to determine than the epochs of maximum and minimum temperatures. This difficulty increases with depth, as the curves become flatter and flatter.

Variation of thermal diffusivity with depth in Poona soil

Table XII gives the amplitudes of soil temperature and the times at which the maximum and minimum temperatures occur at different depths. The last two columns give the values of the thermal diffusivity k calculated from the amplitudes and the values of K the thermal conductivity obtained by multiplying k by the product of the apparent density and the specific heat. The apparent density varies with depth as follows, but the specific heat has a constant value of 0·22.

Depth (cm.)	Apparent density
0	1·0
5	1·9
10	2·1
15	2·3
20	2·3

The thermal conductivity is of the order of 0·0004 at the surface but increases to values lying between 0·0005 and 0·0007, at lower depths, owing to the increase of the apparent density at these depths.

TABLE XII

Depth	Amplitude	Maximum temperature epoch	Minimum temperature epoch	Diffusivity k (calculated from amplitude)	Conductivity K
0 cm.	22·4	1300	0600		
				0·0011	0·00037
5 cm.	9·2	1500	0700		
				0·0015	0·00067
10 cm.	4·3	1700	0800		
				0·0012	0·00060
15 cm.	1·8	2000	0930		
				0·0010	0·00052
20 cm.	0·7	2230	1130		

Seasonal variation of thermal diffusivity

We may now see how the thermal diffusivity of the soil at Poona varies with the season. The mean soil temperatures at different depths from 0 to 50 cm. for different months during the period April 1936 to March 1937 were computed for 0600 and 1400 hours which are the epochs of minimum and maximum soil temperatures respectively at the surface and for 0800 and 1700 hours which are the epochs of minimum and maximum soil temperatures

respectively at a depth of 10 cm. From these the diurnal ranges of soil temperatures for the depths of 0 and 10 cm. were found and the mean thermal diffusivity of the surface layer of the soil, 10 cm. in thickness, calculated. From the records of the Central Agricultural Meteorological Observatory, we know also the rainfall and mean moisture content of this surface layer. The values of diffusivity and of the rainfall and mean moisture content of the first 10 cm. of the soil are given in Table XIII.

TABLE XIII

Monthly variation of diffusivity (between the depths of 0 and 10 cm).

Month	Rainfall in inches	k	Moisture content (per cent on dry basis)
April 1936	0·00	0·0016	7·5
May 1936	0·56	0·0015	7·5
June 1936	3·82	0·0013	12·0
July 1936	1·47	0·0023	25·0
August 1936	1·34	0·0018	13·0
September 1936	7·28	0·0024	25·0
October 1936	0·88	0·0018	15·0
November 1936	2·99	0·0023	21·0
December 1936	0·00	0·0013	13·4
January 1937	0·00	0·0013	8·7
February 1937	0·00	0·0015	7·7
March 1937	0·00	0·0016	5·3

Mean k during the dry season December to May : 0·0015

Mean k during the wet season June to November : 0·0020

During the months December to May there is practically no rainfall and the mean moisture content of the soil between the surface and 10 cm. depth lies between 5 and 13 per cent ; consequently the values of thermal diffusivity also are low, ranging between 0·0013 to 0·0016. The mean diffusivity of the first 10 cm. of the soil during these six dry months of the year is 0·0015. The monsoon sets in in June and the remaining six months of the year are wet. The mean moisture content of the soil is seen to increase up to 25 per cent and the diffusivity from 0·0013 to 0·0024. The mean value of the diffusivity during these six wet months is 0·002.

June has a rainfall of 3·82 in. and yet the value of the diffusivity is seen to be low (0·0013). But we note that the mean moisture content of the soil is also low during this month, viz. 12 per cent, the rainfall having occurred at the end of June. The heavy rainfall at the end of June and further rainfall in July raise the value of the mean moisture content during July to 25 per cent and the diffusivity is also seen to attain the high value of 0·0023 during this month. In September and November again heavy rainfall is recorded, the moisture content of the soil rises in value, and the diffusivity is also seen to be high.

We find therefore that in general the thermal diffusivity of the soil varies directly with its moisture content. This must be attributed to the fact that with increase of moisture, water fills the inter-space between the soil particles, driving away the air which has a low thermal diffusivity.

Thermal diffusivity in relation to surface colour

Table XIV gives the values of thermal diffusivity for the plots A, B, C, D and E during the week January, 8th to 14th, 1935, when all these plots of local Poona soil were exposed to solar radiation with their natural surface colours. The plots A, B, C, D and E have the values of 0·0013, 0·0013, 0·0014, 0·0012 and 0·0013 respectively. The table also gives the values of diffusivity for the plots as 0·0013, 0·0014, 0·0014, 0·0012 and 0·0012 respectively during the week January, 29th to February, 4th, 1935, when the plots B, C, D and E were exposed to solar heating with their surface colours changed by the covers of Trivandrum sand (white), Mekran soil (brown), Sakrand soil (ash-coloured) and Bangalore soil (red), the covers having been applied at 0700 hours on 24th of January 1935. Here we find that all the five plots consisting of the local Poona soil show about the same value of diffusivity whatever be the surface colour, showing that other conditions remaining the same mere change of albedo at the surface makes no alteration in the thermal conductivity in the soil below.

TABLE XIV

Week	Plot	k
1935—January 8—14	A	0·0013
	B	0·0013
	C	0·0014
	D	0·0012
	E	0·0013
January 24th to February, 4th	A	0·0013
	B	0·0014
	C	0·0014
	D	0·0012
	E	0·0012

Variation of thermal diffusivity with soil types

Table XV gives the thermal diffusivity values for the local Poona soil, Trivandrum sand and Sakrand soil, both when the blocks of these soils were exposed to solar heating with their natural surface colours and when their surface colours were equalized by means of a thin cover of the Poona soil.

TABLE XV

Diffusivity—(between the depths of 0 and 10 cm.)

Soil	Before surface treatment	After the surface colours were equalized
	8 May 1936	
Poona soil	0·0014	0·0011
Trivandrum sand	0·0036	0·0032
Sakrand soil	0·0027	0·0024
	20 May 1936	
Poona soil	0·0011	0·0011
Bangalore soil	0·0035	0·0031

Poona soil, Trivandrum sand and Sakrand soil have the diffusivity values of 0·0014, 0·0036 and 0·0027 respectively in their natural condition; and they do not show much difference after the surface treatment.

The table also gives the diffusivity values of 0·0011 and 0·0035 for the Poona soil and Bangalore soil respectively before the soil blocks received the surface treatment. These values are also not affected by the change in the surface colour.

Summary and conclusion

The present paper begins with a description of Poona and its environs and climate (Section I). In the next section the various factors which control the thermal balance at the surface of the ground during the clear season are briefly mentioned. Some typical measurements of the intensity of the radiation from the sun and the sky, the albedo factor which determines the fraction of the radiation actually absorbed by the soil surface, the heat transfer at the surface by conduction, convection and by radiative exchange in the infra-red region of the spectrum are briefly discussed in this section (Section II).

Section III is devoted to an outline of the scheme of experiments discussed later in the paper. In Section IV five experiments on the influence of surface 'covers' on soil temperatures are described. These experiments show how sensitive soil temperatures are to changes of colour or surface

wetness. In many investigations of plant physiologists and agriculturists it is often necessary to alter soil temperatures to suit the requirements of a crop. For example, in higher latitudes where the intensity of solar radiation is low it becomes necessary to make the best use of the weak insolation. In Soviet Russia, for example, the method of covering the soil surface with charcoal powder or coal dust is reported to have been tried with success for making the soil temperatures sufficiently high to sustain a cotton crop. In the hot Indian summer we may often have to keep down soil temperatures to save plants during a droughty period. The use of a thin layer of a white substance like chalk is obvious in such circumstances. The control of soil temperatures by altering the soil cover will be possible only for depths up to 50 cm. or so, as the changes occurring at the surface decrease rapidly with depth.

Section V is devoted to experiments with blocks of different soils which show how the influence of the surface colour may be eliminated by covering all the soils with a thin layer of Poona soil.

The diurnal variations of soil temperatures, the thermal diffusivity of the various soils used in the previous experiments, and the seasonal variation of the thermal diffusivity of Poona soil are discussed in Section VI. It is shown that the diffusivity is not influenced by the surface treatments but increases when the moisture content of the interior of the soil is increased during the wet season.

The investigations discussed in the present paper were conducted under the guidance of Dr L. A. Ramdas, Agricultural Meteorologist, Meteorological Office, Poona. The present writer is grateful to Dr L. A. Ramdas for the suggestion of the problem and to Dr C. W. B. Normand, Director-General of Observatories, for the facilities given for the work at the Meteorological Office, Poona.

REFERENCES

Ramdas, L. A. and Dravid, R. K. (1934). *Current Sci.* **3** No. 6

Ramdas, L. A. and Dravid, R. K. (1936). *Proc. Nat. Inst. Sci. Ind.* **2** No. 3

Ramdas, L. A. and Katti, M. S. (1934). *Ind. J. Agric. Sci.* **4**, part 6

Ramdas, L. A. and Katti, M. S. (1936). *Ind. J. Agric. Sci.* **6**, part 6

Raman, P. K. (1935). *Mem. Ind. Met. Dept.* **26**, part 8

Raman, P. K. (1936). *Proc. Ind. Acad. Sci.* **3**, No. 2

Johnson, N. K. and Davies, E. L. (1927). *Quart. J. Roy. Met. Soc.* **53**, 45

A STUDY ON PLOT SIZE AND SHAPE TECHNIQUE FOR FIELD EXPERIMENTS ON SUGARCANE

BY

B. P. VAGHOLKAR, L.Ag. (Bom.)

Principal Agricultural Officer, Sugarcane Research Scheme for Deccan Padegaon

V. N. APTE, B.Ag. (Bom.)

Superintendent, Padegaon Farm

AND

S. SUBRAMONIA IYER, M.A., F. S. S.

Statistical Assistant, Imperial Council of Agricultural Research

(Received for publication on 19 December 1939)

Introduction

SINCE the inception of the Sugarcane Research Scheme at Padegaon, financed by Imperial Council of Agricultural Research, experiments have been laid down on modern lines of field technique propounded by Dr. Fisher. To suit the local conditions, an experimental gross plot size of 54·45 ft. × 32 ft. = 4 cents (4/100 acre) was considered convenient for experiments in this farm. This plot size covered eight rows of cane 4 ft. apart and omitting one row on either side of the plot for border effect, and 4·5 ft. on either end a net plot of 2·5 cents (i.e. 1/40th of an acre) was obtained. The plant population varied from 600 to 1000 in this unit plot-size depending on the variety. The main conditions of soil and growing of the crop in this area is as follows, which differ from conditions of dry crop in Northern India :—

(*1*) *Topography.*—The soil is extremely undulating and is found to have a gradient varying from 1 in 100 to 1 in 300 on both sides which is not found in the United Provinces or Bihar where gradients are 1 in 1,000 to 2,000.

(*2*) *Cane growing.*—Cane is required to be irrigated throughout the year at intervals of ten days and hence cane is planted 4 ft. apart. Regular and even distribution of irrigation water is important for this crop.

After one year's experience with the above plot size, the distribution of water with varying gradients in the farm was found to be regular and as a result crop growth was also found perfectly uniform. The uniform growth of the crop in a plot resulting from even distribution of irrigation water removed one cause of variability and gave satisfactory results.

Still it was thought necessary to conduct a special uniformity trial to have convincing proof about the soundness of the plot size already laid down and to see whether the plot size could not be further reduced, which information would be useful in laying out future experiments.

Material

Two areas 'A' and 'B' were planted with Co 360 cane in the first week of March 1934. A short description of the two plots showing the details of topography cultural operations, etc. is given below :—

	Block A	Block B	Remarks
(1) Size . .	E-W 192 ft. × S-N 253·4 ft. equivalent to 1 acre 4·6 gunthas	E-W 132 ft. × N-S 483·4 ft. equivalent to 1 acre 18·6 gunthas.	
(2) Topography .	Depth of soil 9 in. to 12 in. Depth of sub-soil 8 in. to 9 in. Lower strata of porous murum well drained	Depth of soil 9 in. to 12 in. Depth of sub-soil 8 in. to 9 in. Lower strata of porous murum well drained	
(3) Method under which cane was grown :—			
(1) Time of planting	7 March 1934 . .	5 March 1934	
(2) Distance between rows	4 feet	4 feet	
(3) Seed rate .	10,000 sets of three eye-buds each per acre.	10,000 sets of three eye-buds each per acre	
(4) Number of irrigations	33	35	
(5) Manuring .	Farmyard manure at 25 carts per acre applied on 19th February 1934. 150 lb. of nitrogen was applied as top dressing in the form sulphate of ammonia and cake in the usual Manjri standard method.	Farmyard manure at 25 carts per acre applied on 17th February 1934. 150 lb. of nitrogen was applied as top-dressing in the form of sulphate of ammonia and cake in the usual Manjri standard method.	Variety Co 360 (flowering)
(6) Earthing up	The crop was hand weeded and earthing up was done by a plough on 1st July 1934.	The crop was hand weeded and earthing up was done by a plough on 2nd July 1934	
(7) Date of harvest.	The crop was cut in strips of 10 ft. from 21st January 1935 to 26th January 1935.	The crop was cut in strips of 10 ft. from 4th February 1935 to 12th February 1935.	
(8) Yield in tons	35·97 per acre . .	26·6 per acre	

For purposes of this study after discarding guard rows all round, 32 rows each 240 feet long were taken from plot A, and 30 rows each 400 feet long from plot B. The rows were cut in sections of 10 feet length. Thus there were 768 ultimate units (10 ft. × 4 ft.) from plot A and 1200 units (10 ft. × 4 ft.) from plot B.

Statistical analysis

The distribution of yields from unit plots from both the blocks were found to be nearly normal as the following constants show :—

Plot A : $g_1 = -0{\cdot}1059 \pm 0{\cdot}0839$
$g_2 = 0{\cdot}861 \pm 0{\cdot}167$
Plot B: $g_1 = 0{\cdot}064 \pm 0{\cdot}068$
$g_2 = -0{\cdot}050 \pm 0{\cdot}137$

The 768 units of plot ' A ' were grouped to give plots one row, two rows, four rows and eight rows wide and 10 ft., 20 ft., 30 ft., 40 ft., 60 ft., 80 ft. and 120 ft. long. The plots so formed were then grouped together to form four plot and eight plot (see below) blocks in different ways.

In the case of 1,200 units of plot B, the unit plots were grouped to give plots one row, two rows, three rows, five rows, six rows and ten rows wide and 10 ft., 20 ft., 40 ft., 50 ft., 80 ft. and 100 ft. long. Blocks were now formed by taking five plots together across rows and along rows.

In all cases the usual method of analysis of variance was adopted to remove the variation between blocks and thence to calculate the percentage standard error per plot for the particular case considered. In almost all cases there was an appreciable reduction in the variance by this process of elimination of major soil differences.

Table I gives the percentage standard error per plot (coefficient of variation) for both the fields for the different kinds of blocks. For field A, four types of blocks have been considered, viz. four-plot blocks across rows (i.e. the plots lying in a line at right angles to the direction of the rows), four plot blocks (in a line) along the direction of rows, four-plot blocks in two rows (compact), and eight plot blocks (compact only). In the last case the blocks have been taken in as compact a form as possible.

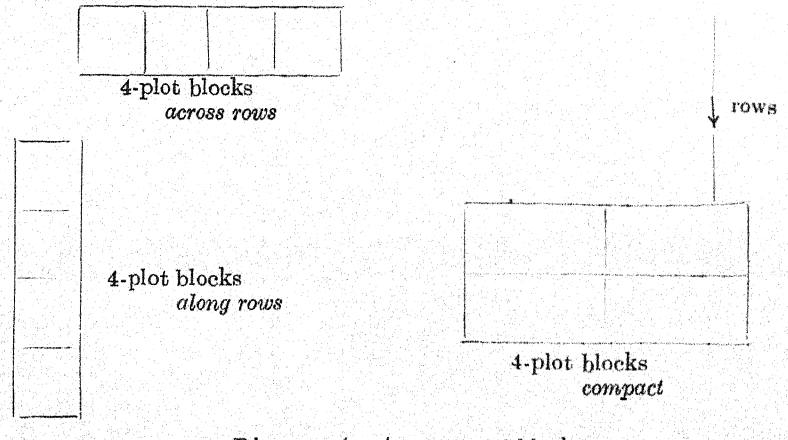


Diagram showing types of blocks.

For field B, five-plot blocks have been taken along rows and across rows

As has been found usual in similar analyses with other crops as well as sugarcane (for a fairly complete bibliography on uniformity trial data see Cochran [1937] and in addition Hutchinson and Panse [1935] and Macdonald *et al* [1939]), there is a gradual decrease in the values of the percentage error per plot by an increase either in the length of the rows or by the inclusion of greater number of rows (i.e. by increasing the width of the plot). It is seen that the reduction in variation is more rapid by increasing the length of rows. There is also a definite advantage in the inclusion of greater number of rows per plot up to say between four and eight rows. In the latter case it is however evident that there is no proportionate gain in precision ; for instance in doubling the size of plot from four rows to eight rows, the precision is not increased two-fold. These tables indicate that the usual plot size adopted at the station (vide introduction) is quite satisfactory from the point of view of precision, and any reduction in the size would diminish the accuracy of the comparisons.

As regards the method of formation of blocks for removing major differences in soil fertility, these tables show that in the case of small plots there is very little to choose as to whether the blocks should be taken across rows, along rows or compact. In the case of bigger plots (of the type usually adopted in field experiments) there seems to be a slight advantage in taking the plots across the direction of rows. In field B however, five plot blocks along the direction of rows appeared better than across the rows.

There is also very little difference in the standard of accuracy by having eight plot blocks or four plot blocks as far as the present data are concerned.

In Table II plots of the same shape (i.e. length : breadth ratio) are grouped together and in Table III plots of the same size, but of different shapes. For any particular shape, the bigger the plot, the less the variation within the limits studied in this paper.

Table III shows that contrary to the usual, amongst plots of a given size up to about 1/90 acre, the longer plots appear to vary more than the shorter plots, and also when the plots are widened by increasing the number of rows (the width being greater than the length) the variation is as high as in the case of long plots. When the plot size is greater than 1/90 acre, the longer plots, in general, show less variation than the shorter plots. As the usual experimental plots fall within this range, the conclusion that fairly long plots are preferable to square plots seems to be supported by the present data. There seems to be also no advantage in having a large number of short rows per plot for sugarcane field experiments, i.e. for a given plot shape it is seen that it is more advantageous to have the longer dimension of the plot along the direction of rows than across. Similar results were obtained by Hutchinson and Panse [1935] working with Malvi mass-selected cotton data at Indore.

Table IV gives the number of replications and area of land required to give a standard error of 2 per cent of the mean. This means that differences of over 6 per cent of the mean can be taken to be significant ($P = 0{\cdot}05$). The number of replications and area of land required is of course dependent on the standard of accuracy required. When a smaller degree of accuracy is sufficient (say differences of 12 per cent of the mean), standard error has

only to be 4 per cent of the mean and the number of replications will be half of what it is in Table IV.

A comparison of Tables IV A and IV B shows that the standard error and consequently the number of replications and area of land required for a given degree of accuracy are largely dependent on the amount of heterogenecity present. Field B as a whole shows greater variation for the whole range of plot sizes considered and hence the number of replications is also found to be comparatively high.

Efficiency per unit area of land

Table V gives the relative efficiencies of plots in the use of land. The usual method has been employed in the calculation of these figures. The efficiency of a particular plot has been obtained by multiplying the percentage variance per plot by the number of units used to make up the plot ('unit' referring to the smallest plot size used in the present data), and taking the reciprocal. The smaller plots are seen to be comparatively more efficient than bigger plots although from the point of view of agricultural convenience no one would lay out experiments with too small plots. From field A, (four plot blocks) it will be seen that two-row plots 60 ft. to 80 ft. long are almost as efficient as the smallest-sized plots. When blocks are taken across rows, plots of 80 ft. length and eight rows width also seem to be quite efficient. With eight plot blocks, however there seems to be no advantage in increasing the number of rows per plot beyond four. Here also the optimum length of rows appears to be 60 to 80 ft. which is somewhat longer than the usual plot length. On the basis of these figures also it appears that the usual plot size adopted in this station is fairly satisfactory.

Field B shows that with five plot blocks the efficiencies of the bigger-sized plots are comparatively very much lower. As a matter of fact, in this area five plot blocks and ten plot blocks on the whole gave much higher standard errors as compared to blocks with two, four etc. plots. To study the influence of increasing the size of block, keeping the same plot size, standard errors were calculated separately for plot of size 40 ft. × 20 ft. and the results are given below :—

Number of plots per block	Per cent standard error
2	11·86
3	11·10
4	11·66
5	17·08
6	12·25
10	16·48
12	12·72

This shows that for some particular numbers of plots per block, the precision may be high, the optimum number depending on the nature of the field itself. In this field, there is very little difference between two, three or four plot blocks or even six or twelve plot blocks. Only five or ten plot blocks appear to show higher variation. This is an interesting conclusion, especially as the

number of plots per block has assumed a new importance with the advent of the 'incomplete block systems of lay-out' the quasi-factorial as well as the symmetrical types.

Summary

The results of a uniformity trial on sugarcane conducted in two fields at Padegaon have been studied mainly with a view to examine the satisfactoriness of the usual plot size and shape adopted at the station, viz. (54·44 ft. × 32 ft.) (eight rows 4 ft. apart) and it is found that under the conditions prevailing here, there seems to be no need for any appreciable change.

2. When the plot size is greater than 1/90 acre, in general, the longer plots show less variation than shorter plots. That fairly long plots are preferable to square plots is thus shown by the present data.

3. When four plot blocks are considered, it is found that two-row plots 60 ft. to 80 ft. long are almost as efficient as the smallest sized plots. When blocks are taken across rows, plots of 80 ft. length and eight rows width also seem quite efficient.

4. With eight plot blocks there appears to be no advantage in increasing the number of rows per plot beyond four.

5. It is also seen that there need be no restriction in the number of plots per block which might vary from two up to twelve depending upon the experimental treatments.

Acknowledgements

The scheme is financed by the Imperial Council of Agricultural Research to whom our thanks are due. We are also thankful to Rao Bahadur M. Vaidyanathan for his very valuable advice in the preparation of this paper.

REFERENCES

Cochran, W. G. (1937). *Suppt. to J. Roy. Stat. Soc.* **4**, 233

Hutchinson, J. B. and Panse, V. G. (1935). *Ind. J. Agri. Sci.* **5**, 523.

MacDonald, D., Fielding, W. L. and Raston, D. F. (1939). *J. Agric. Sci.* 29

TABLE I

Standard errors per cent for plots of different sizes and shapes

Row lengths in feet	Number of rows			
	1	2	4	8
	Field A.—4-plot blocks across rows			
10	26·00	18·13	15·13	12·44
20	19·53	12·94	9·59	7·55
30	17·04	12·05	9·00	6·29
40	15·92	11·18	7·18	6·26
60	12·11	7·90	6·33	5·24
80	9·76	6·66	5·69	3·40
120	9·15	6·27	4·85	..
	Field A.—4-plot blocks along rows			
10	25·64	18·59	15·34	12·28
20	19·65	13·37	9·90	7·46
30	17·09	12·14	9·25	6·43
60	12·05	9·01	7·21	5·57
	Field A.—4-plot blocks compact			
10	27·22	18·54	15·25	12·67
20	19·58	13·05	9·24	7·38
30	17·52	12·11	8·91	6·43
40	16·19	12·11	7·27	6·01
60	12·15	8·27	6·33	5·43
120	9·83	7·15	5·01	..

TABLE I—*contd.*

Row lengths in feet	Number of rows			
	1	2	4	8
Field A.—8-plot blocks compact				
10	27·02	18·52	14·96	10·40
20	19·38	12·96	9·75	8·05
30	17·22	12·05	9·12	6·76
40	15·48	9·67	7·88	6·74
60	12·04	8·27	6·68	5·59
80	9·61	7·42	5·74	..
120	9·04	6·63	5·11	..

Row lengths in feet	Number of rows					
	1	2	3	5	6	10
Field B.—5-plot blocks across rows						
10	31·44	23·55	24·10	16·83	15·17	12·57
20	27·98	18·82	16·51	13·65	12·22	10·25
40	24·24	19·30	18·28	17·08	15·76	15·40
50	..	..	..	*15·79	..	*15·04
80	21·41	16·89	15·88	14·97	14·30	13·81
100	..	..	..	*15·05	..	*14·32
Field B.—5-plot blocks along rows						
10	36·20	24·13	24·12	..		12·30
20	29·19	18·95	16·37	..		11·81
40	21·38	16·20	12·88	..		9·34
50	20·20	13·62	11·55	†8·50		8·88
80	18·05	12·03	10·57	..		8·38
100	16·01	10·88	8·65	†14·81		7·07

* 4-plot Blocks (across).
†4-plot Blocks (compact).

TABLE II-A

(Field A)

Standard errors per cent of plots of different sizes arranged according to shape

Plot shape (length : breadth)	Plot size (acre)	4-plot block			8-plot blocks
		across rows	along rows	compact	
2·5 : 1	1/1089	26·00	25·64	27·22	27·02
	1/272	12·94	13·37	13·05	12·96
	1/68	7·18	..	7·27	7·88
	1/17	3·40	..	..	..
5 : 1	1/544	19·53	19·65	19·58	19·38
	1/36	11·18	..	12·11	9·67
	1/34	5·69	..	..	5·74
7·5 : 1	1/363	17·04	17·09	17·52	17·22
	1/90	7·90	9·01	8·27	8·27
	1/22	4·85	..	5·01	5·11
10 : 1	1/272	15·92	..	16·19	15·48
	1/68	6·66	..	..	7·42
15 : 1	1/181	12·11	12·05	12·15	12·04
	1/45	6·27	..	7·15	6·63
20 : 1	1/36	9·76	..	..	9·61
30 : 1	1/91	9·15	..	9·83	9·04
1·25 : 1	1/544	18·13	18·59	18·54	18·52
	1/136	9·59	9·90	9·24	9·75
	1/34	6·26	..	6·01	6·74
3·75 : 1	1/181	12·05	12·14	12·11	12·05
	1/45	6·33	7·21	6·33	6·68
	1/11	..	..	..	..
·625 : 1	1/272	15·13	15·34	15·25	14·96
	1/68	7·55	7·46	7·38	8·50
1·875 : 1	1/90	9·00	9·25	8·91	9·12
	1/22	5·24	5·57	5·43	5·59
·3125 : 1	1/136	12·44	12·28	12·67	10·40
9375 : 1	1/45	6·29	6·43	6·43	6·76

TABLE II-B
(*Field B*)

Standard errors per cent of plots of different sizes arranged according to shape

Plot shape (length : breadth)	Plot size (acre)	5-plot blocks	
		across	along
25 : 1	1/109	..	16·01
20 : 1	1/136	21·41	18·05
12·5 : 1	1/218	..	20·20
10 : 1	1/272	24·24	21·38
	1/68	16·89	12·03
5 : 1	1/544	27·29	29·19
	1/136	19·30	16·20
	1/22	*15·05	†14·81
2·5 : 1	1/1089	34·44	36·20
	1/272	18·82	18·95
	1/44	*15·79	†8·50
	1/11	*14·31	..
1·25 : 1	1/544	23·55	24·13
	1/22	*15·04	..
6·25 : 1	1/109	..	13·62
12·5 : 1	1/54	..	10·88
·5 : 1	1/218	16·83	..
	1/105	10·25	..
.25 : 1	1/109	12·57	..
.83 : 1	1/363	24·10	24·12
	1/90	12·22	11·81
1·7 : 1	1/181	16·51	16·37
	1/45	15·76	9·34
3·3	1/90	18·28	12·88
	1/22	14·30	8·38
4·2 : 1	1/73	..	11·55
	1/18	..	7·07
6·7 : 1	1/45	15·88	10·57
8·3 : 1	1/36	..	8·65
1 : 1	1/109	13·65	..
	1/27	15·40	..
2 : 1	1/54	17·08	..
	1/13	13·81	..
4 : 1	1/27	14·97	..
2 : 1	1/36	..	8·88
·4 : 1	1/181	15·17	12·30

*4-plot blocks (across). † 4-plot blocks (compact).

TABLE III-A

(Field A)

Standard errors per cent of plots of different shapes arranged according to size

Plot size	Plot shape (length : breadth)	4-plot blocks			8-plot blocks
		across rows	along rows	compact	
1/1089	2·5 : 1	26·00	25·64	27·22	27·02
1/544	5 : 1	19·53	19·65	19·58	19·38
	1·25 : 1	18·13	18·59	18·54	18·52
1/363	7·5 : 1	17·04	17·09	17·52	17·22
1/272	10 : 1	15·92	..	16·19	15·48
	2·5 : 1	12·94	13·37	13·04	12·96
	·625 : 1	15·13	15·34	15·25	14·96
1/181	15 : 1	12·11	12·05	12·15	12·04
	3·75 : 1	12·05	12·14	12·11	12·05
1/136	20 : 1	9·76	..	..	9·61
	5 : 1	11·18	..	12·11	9·67
	1·25 : 1	9·59	9·90	9·24	9·75
	·3125 : 1	12·44	12·28	12·67	10·40
1/90	30 : 1	9·15	..	9·83	9·04
	7·5 : 1	7·90	9·01	8·27	8·27
	1·875 : 1	9·00	9·25	8·91	9·12
1/68	10 : 1	6·66	..	..	7·42
	2·5 : 1	7·18	..	7·27	7·88
	·625 : 1	7·55	7·46	7·38	8·50
1/45	15 : 1	6·27	..	7·15	6·63
	3·75 : 1	6·33	7·21	6·33	6·68
	·9375 : 1	6·29	6·43	6·43	6·76
1/34	5 : 1	5·69	..	..	5·74
	1·25 : 1	6·26	..	6·01	16·74
1/22	7·5 : 1	4·85	..	5·01	5·11
	1·875 : 1	5·24	5·57	5·43	5·59
1/17	2·5 : 1	3·40	..	..	..
1/11	3·75 : 1	..	..	.	..

TABLE III-B
(*Field B*)
Standard errors per cent of plots of different shapes arranged according to size

Plot size (acre)	Plot shape (length : breadth)	5-plot blocks	
		across rows	along rows
1/1089	2·5 : 1	34·44	36·20
1/544	5 : 1	27·98	29·19
	1·25 : 1	23·55	24·13
1/363	·83 : 1	24 10	24.12
1/272	10 : 1	24·24	21·38
	2·5 : 1	18·82	18·95
1/218	12·5 : 1	..	20·20
	0·5 : 1	16·83	..
1/181	1·7 : 1	16·51	16·37
	·4 : 1	15·17	12·30
1/136	20 : 1	21·41	18·05
	5 : 1	19·30	16·20
1/109	25 : 1	..	16·01
	6·25 : 1	..	13·62
	1 : 1	13·65	..
	·25 : 1	12·57	..
1/105	0·5 : 1	10·25	..
1/90	3·3 : 1	18·28	12·88
	0·83 : 1	12·22	11·81
1/73	4·2 : 1	..	11·55
1/68	10 : 1	16·89	12·03
1/54	12·5 : 1	..	10·88
	2 : 1	17·08	..
1/45	6·7 : 1	15·88	10·57
	1·7 : 1	15·76	9·34
	2·5 : 1	*15·79	†8·50
1/36	8·3 : 1	..	8·65
	2·1 : 1	..	8·88
1/27	4 : 1	14·97	..
	1 : 1	15·40	..
1/22	5 : 1	*15·05	†14·81
	3·3 : 1	14·30	8·38
	1·25 : 1	*15·04	..
1/18	4·2 : 1	..	7·07
1/13	2 : 1	13·81	..
1/11	2·5 : 1	*14·31	..

* 4-plot blocks (across). † 4-plot blocks (compact).

TABLE IV-A

(Field A)

Number of replications and area of land required to give a standard error of 2 per cent of the mean

Plot size (acre)	Plot shape (length : breadth)	Number of replications (4-Plot Blocks)			8-plot blocks.	Total area (4-plot blocks)			8-plot blocks
		Across rows	Along rows	Compact		Across rows	Along rows	Compact	
1/1089	2·5 : 1	169	164	185	169	0·62	0·60	0·68	1·24
1/544	5 : 1	95	97	96	94	0·70	0·71	0·70	1·38
	1·25 : 1	81	86	86	86	0·59	0·63	0·63	1·26
1/363	7·5 : 1	73	73	77	74	0·80	0·80	0·85	1·63
1/272	10 : 1	63	...	66	60	0·93	...	0·97	1·76
	2·5 : 1	42	45	43	42	0·62	0·66	0·63	1·23
	·625 : 1	57	59	58	5[illegible]	0·84	0·87	0·85	1·65
1/181	15 : 1	37	36	37	36	0·82	0·79	0·82	1·59
	3·75 : 1	36	37	37	36	0·79	0·82	0·82	1·59
1/136	20 : 1	24	...	...	23	0·71	...	...	1·35
	5 : 1	31	...	37	23	0·91	...	1·09	1·35
	1·25 : 1	23	25	21	24	0·68	0·73	0·62	1·41
	·3125 : 1	39	38	40	27	1·15	1·12	1·18	1·59
1/90	30 : 1	21	...	24	20	0·93	...	1·07	1·78
	7·5 : 1	16	20	17	17	0·71	0·89	0·[illegible]5	1·51
	1·875 : 1	20	21	20	21	0·89	0·93	0·89	1·87
1/68	10 : 1	11	...	...	14	0·65	...	...	1·65
	2·5 : 1	13	...	13	15	0·76	...	0·76	1·76
	·625 : 1	14	14	14	18	0·82	0·82	0·82	2·12
1/45	15 : 1	10	...	13	11	0·89	...	1·15	1·95
	3·75 : 1	10	13	10	11	0·89	1·15	0·89	1·95
	·9375 : 1	10	10	10	11	0·89	0·89	0·89	1·95
1/34	5 : 1	8	...	...	8	0·94	...	...	1·88
	1·25 : 1	10	...	9	11	1·18	...	1·06	2·59
1/22	7·5 : 1	6	...	6	6	1·09	...	1·09	2·18
	1·875 : 1	7	8	7	8	1·27	1·45	1·27	2·91
1/17	2·5 : 1	3	...	...	...	0·71	...	...	...
1/11	3·75 : 1	...	...	...	...	...	...	...	...

TABLE IV-B

(Field B)

Number of replications and area of land required to give a standard error of 2 per cent of the mean

Plot size (acre)	Plot shape (length : breadth)	Number of replications (5-plot blocks)		Total area	
		Across rows	Along rows	Across rows	Along rows
1/1089	2·5 : 1	296	328	1·36	1·50
1/544	5 : 1	196	213	1·80	1·96
	1·25 : 1	139	145	1·28	1·33
1/363	0·83 : 1	145	145	2·00	2·00
1/272	10 : 1	147	114	2·70	2·09
	2·5 : 1	88	90	1·62	1·65
1/218	12·5 : 1	..	102	..	2·34
	0·5 : 1	71	..	1·63	..
1/181	1·7 : 1	68	67	1·88	1·85
	0·4 : 1	57	38	1·57	1·05
1/136	20 : 1	114	81	4·19	2·98
	5 : 1	93	66	3·42	2·43
1/109	25 : 1	..	64	..	2·93
	6·25 : 1	..	46	..	2·11
	1 : 1	46	..	2·11	..
	0·25 : 1	39	..	1·79	..
1/105	0·5 : 1	26	..	1·24	..
1/90	3·3 : 1	83	41	4·61	2·28
	0·83 : 1	37	35	2·05	1·94
1/73	4·2 : 1	..	33	..	2·26
1/68	10 : 1	71	36	5·22	2·65
1/54	12·5 : 1	..	29	..	2·68
	2 : 1	73	..	6·76	..
1/45	6·7 : 1	63	28	7·00	3·11
	1·7 : 1	62	22	6·89	2·44
	2·5 : 1	*62	†18	5·51	1·60
1/36	8·3 : 1	..	19	..	2·64
	2·1 : 1	..	20	..	2·78
1/27	4 : 1	56	..	10·37	..
	1 : 1	59	..	10·92	..
1/22	5 : 1	*57	†55	*10·36	†10·00
	3·3 : 1	51	17	11·59	4·86
	1·25 : 1	*56	..	*10·18	..
1/18	4·2 : 1	..	12	..	3·33
1/13	2 : 1	48	..	18·46	..
1/11	2·5 : 1	*51	..	*18·54	..

*4-plot blocks (across). †4-plot blocks (compact.)

TABLE V

Efficiency of plots in use of land

Row lengths in feet	Number of rows			
	1	2	4	8
Field A.—4-plot blocks across rows				
10 . .	100	102	98	55
20 . .	88	101	92	74
30 . .	77	77	69	71
40 . .	66	67	82	54
60 . .	76	90	70	51
80 . .	89	95	65	91
120 . .	67	72	60	..
Field A.—4-plot blocks along rows				
10 . .	100	95	69	54
20 . .	85	92	84	74
30 . .	75	74	64	66
40 . .	..	..	..	..
60 . .	75	67	53	44
80 . .	..	..	..	..
120 . .	..	..	..	..
Field A.—4-plot blocks compact				
10 . .	100	107	79	58
20 . .	96	108	108	85
30 . .	80	84	78	75
40 . .	70	63	87	64
60 . .	83	90	77	52
80 . .	..	..	..	..
120 . .	64	60	63	..

TABLE V—*contd.*

Row lengths in feet	Number of rows			
	1	2	4	8
Field A.—8-plot blocks compact				
10	100	106	81	84
20	97	109	96	70
30	82	84	73	66
40	76	97	73	50
60	84	89	68	49
80	99	83	69	..
120	74	69	58	..

Row lengths in feet	Number of rows					
	1	2	3	5	6	10
Field B.—5-plot blocks across rows						
10	100	107	68	84	86	75
20	76	84	72	64	66	56
40	50	40	29	20	20	12
50	..	..	..	*19	..	*10
80	32	26	19	13	12	8
100	..	..	..	*10	..	*6
Field B.—5-plot blocks along rows						
10	100	112	75	..	144	
20	77	91	81	..	78	
40	72	62	66	..	62	
50	64	71	65	†72	55	
80	50	56	49	..	39	
100	51	55	58	†12	44	

*4-plot blocks (across). †4-plot blocks (compact).

INTERSPECIFIC HYBRIDIZATION BETWEEN ASIATIC AND NEW WORLD COTTONS *

BY

K. C. AMIN, B.Ag.

Department of Agriculture, Bombay

(Received for publication on 27 May 1939)

(With Plates IV and V)

Introduction

IT is a well known fact that cotton presents two taxonomically different groups, associated with differences in chromosome numbers. Cultivated cottons have been grouped as Asiatics or Old World cottons with 13 pairs of chromosomes and New World cottons with 26 pairs of chromosomes. As a rule, hybridization within one group leads to fertility and between the groups to sterility.

Recent cytological researches have brought to light some new facts concerning various wild species of cottons, and it has been shown [Skovsted, 1934] that New World cottons with $2n=52$ chromosomes are probably amphidiploids resulting from chromosome doubling in a hybrid between an Asiatic cotton with $2n=26$ and a wild American cotton with $2n=26$ chromosomes, though recently some doubts in this connection have been expressed by Gates [1938].

In Asiatic group, Surat cottons represent the high water level of quality cottons in India. The highest spinning value yet attained in any of the types of Indian cottons is 40's warp counts and strains spinning to this limit are in cultivation. To increase this spinning quality to a range higher than 40's is an important economic problem. There are no other types of Asiatic cottons available which can be utilized for crossing in order to increase the spinning value above this limit.

On the other hand, New World cottons including various American, Egyptian, and Sea-Island types which are reputed for long, silky and strong fibre (and consequently possessing very high spinning value), bigger bolls and greater vigour have been imported and efforts made to introduce them in general cultivation in various cotton growing tracts of India. But such attempts have in most cases met with indifferent success, especially with regard to longest stapled varieties, i.e. Sea-Island and Egyptian.

In view of this situation, it has often been suggested, 'why not cross American and Indian types and try to get a much better type for cultivation in India'. The idea of combining the good qualities of both these groups of cotton in a hybrid has always been a fascinating goal for many workers in cotton since long.

* This work has been recently financed by the Indian Central Cotton Committee at a cost of Rs. 14,014, spread over a period of five years commencing from 1 November 1938. The aim of the scheme is to combine the hardiness and adaptability of Asiatic cottons with the superior fibre qualities of the New World cottons.

Previous work

The recorded evidence of efforts at hybridization between Asiatic and New World cottons begins with Major Trevor Clarke's experimental work in the seventies of the nineteenth century. He failed in the attempt and, as quoted by Watt, is reported to have said, 'I strongly doubt the possibility of any cross between exotics and Indian sorts, and fear you will be disappointed in this respect when your plants come to perfection'. However, it is curious that Watt himself took it for granted that hybridization between these two groups was possible [Harland, 1928], and the natural evolution of some forms of cottons is attributed by him to this source. Mell [1897] reported complete failure in obtaining successful hybrids between American and Indian types. Webber [1905] was unable to cross 'Aiden' cotton (as quoted by him), which he classified as *G. herbaceum*, with varieties of either Sea-Island (*G. barbadense*) or Upland (*G. hirsutum*). Gammie appears to have been the first to obtain successful hybrids between these two groups, as reported by Watt [1907] and by himself [Gammie, 1905]. He produced hybrids between *G. hirsutum* × *G. obtusifolium*., *G. hirsutum* × *G. roseum* and *G. arboreum* × *G. hirsutum*, but nothing further is known about the results of his work.

The main credit must go to Zaitzev, who tackled the problem systematically and was able to get two hybrids between *G. herbaceum* × *G. hirsutum*. He crossed nearly one thousand flowers by his method of complete emasculation of removing the staminal sheath and obtained two hybrids thus giving 0·2 per cent success. He observed that only a few seeds were obtained per boll in case of crossed bolls. Five more hybrids of the same parentage were also observed by his assistants in the field as natural hybrids. As all his hybrids proved completely sterile, he abandoned the hope of getting anything further from them and finally regarded them as useless.

Accordingly, many workers endeavoured to get hybrids between these groups but were unsuccessful and, in consequence, it came to be generally believed that hybridization between the two groups was not possible or that hybrids, if produced, were sterile and of no further potential value. However, Vycotski [1930] reported upon the revival of such work on a large scale at Taskhent, and stated that the percentage of natural crossing between varieties differing in chromosome numbers was generally less than 0·003 per cent. Later, Kanash [1932] reported that he had been able to get 56 hybrids between various American and Indian types and had succeeded in inducing fertility in them by backcrossing. He observed that the percentage of successful hybrids in individual classes varies to a somewhat high degree, i.e., from 0·13 to 2·5 per cent; this variation being observed both between different crosses and in one and the same cross in different years. On the whole, success percentage varied from 0·011 to 2·25. He gives details of the phenomenon of occurrence of one seed in hybrid bolls as observed by him. Nakatomi [1931] got six hybrids between Asiatic and New World cottons. He crossed thousands of flowers, and his percentage success seems to be very low. Longley [1933] reported a hybrid between these two groups. Feng [1935] stated that he had obtained a few hybrids between *G. arboreum* and *G. nanking* with *G. barbadense* and *G. hirsutum*. He crossed 1,700 flowers and got seven hybrids, a percentage success of 0·4. He also observed the phenomenon of the occurrence

of one seed per boll in case of crossed bolls. Harland [1932, 1935] obtained two hybrids between *G. barbadense* and *G. arboreum* and by back-crossing to the higher chromosome parent, succeeded in getting fertile derivatives from the cross, introducing at the same time some of the genes from the Asiatic cotton into the other group. He crossed thousands of flowers and his success percentage seems to be very low. Szymanek [1932, 1936] reports to have got hybrids between these groups, but, from the complete fertility of the hybrids, the behaviour of the hybrid progeny and the results of cytological studies (cited by Skovsted), it seems that there was some doubt about the classification of the cottons he had under experimentation. Skovsted and Webber have done extensive scale hybridization between different groups of cotton. This work, together with cytological studies carried out by them, has thrown considerable light on the problem of the relationship between different species of cotton.

In India, Desai [1927] was the first worker to secure a hybrid between *G. hirsutum* × *G. herbaceum* and reported having obtained some successful first back crosses. Patel [1933] describes a hybrid obtained by him between *G. purpurascens* and *G. herbaceum*. He crossed only fifty flowers and secured one hybrid from one seed obtained from a single hybrid boll. The hybrids obtained by these two workers died on account of accidents and nothing further was achieved by them. Patel, G. B. (unpublished) produced a hybrid between *G. hirsutum* and *G. herbaceum* and Patel, P. L. (unpublished) also secured three hybrids of the same parentage at Broach. Few plants from backcrosses with *G. hirsutum* were also obtained and are at present growing at Broach. Ramanathan [1932] secured a hybrid between Karungani (*G. arboreum*) × Cambodia (*G. hirsutum*) which died later on due to stem weevil attack.

Work at Surat

As a result of the impetus derived from the successful work of interspecific hybridization carried on in other crops and the successes obtained by Harland and Russian workers, research work in this direction was started in 1932 at Surat. Dr Burns, the then Director of Agriculture, Bombay Province, expressed his opinion that continued efforts should be made to obtain a fertile hybrid between Indian and American types of cotton in order to overcome the comparatively narrow limits set up by selection and crossing within either group. Preliminary information about the work was published by Thakar and Amin [1936] and Amin [1937], and the present paper is a comprehensive account of the whole investigation ever since it was started including the results previously published.

(*a*) *Material*

To begin with, work was started with a few Dharwar American and Punjab American types (*G. hirsutum*) grown on the station for the purpose, as it was considered that these types would be better suited to the climate than others. Later on, Sea-Island, Maarad (*G. barbadense*), and a few tree cottons (*G. religiosum* and *G. barbadense*) were added. The Asiatic types used were 1027 ALF and White Flower (*G. herbaceum*) and Gaorani. 6. and Red Arboreum (*G. arboreum*).

(*b*) *Methods*

In the beginning, the technique of hybridization was the one that is commonly followed, viz. emasculation by removing anthers with a pair of forceps and protecting the emasculated flower with a paper bag. Modifications of this technique were made in course of the work, and later on, the method advocated by Doak [1934] was adopted, i.e. the splitting of the staminal column with the finger nail and the removal of the entire corolla with the whole andræcium in a single piece. This method removes everything from the flower except the pistil which is thus exposed completely. It also ensures less chance of pollen remaining on the corolla and andræcium on account of chance breaking of anthers. The flowers were emasculated in the evening of the day preceding anthesis and enclosed in paper bags. Pollination was done next morning. This method however was found to work well with American types in which the flowers are bigger than in Indian types where the operation of the removal of the corolla by the finger nail proved to be liable to compress the delicate soft overy or to rupture the thin style. Hence, with Indian cottons, emasculation was done by removing the corolla with a scalpel and the anthers by a pair of forceps. This operation was done early in the morning of the day of anthesis and is facilitated by the large size of the bud and by the fact that the anthers in these cottons do not burst so early as in New World cottons.

The F_1 hybrids are self-sterile and in order to utilize the large number of flowers opening on them, dusting of open flowers with the pollen of parents was done for backcrossing and the crossed flowers were left unprotected. A careful watch was kept on developing bolls which were protected against damage by boll worms with paper bags with their mouths tied with a piece of thread. The thread of the label, attached to the boll for identification was used for the purpose. This technique has been found to give satisfactory results. In adition, all flowers, other than pollinated ones, were removed from the parent plants. This operation prolonged flowering and facilitated the work of hybridization. The seedlings were first raised in pots under protection and then transplanted in the field.

(*c*) *Results of experiments, 1932-1938*

To begin with, methods advocated by Desai [1927] were given a trial, but without success. Desai [1927] obtained 12, 20 and 0·5 per cent success by painting the stigmas with citric acid solution, citric acid *plus* cane sugar solution and without any treatment of the stigma respectively. No success was however obtained by the author by the use of citric acid solution or cane sugar solution alone or in combination. Kanash [1932] and Webber [1936] also failed to get any results by painting stigma with various solutions and the latter thinks that the reported success might be due to the development of parthenocarpic capsules. The writer agrees with Webber as he found that parthenocarpy is pronounced in cottons and one gets bolls resembling empty shells with a few immature seeds, some of which even show slight immature lint developed on them particularly in those cases where only a few bolls are left developing on the plants.

Crossing and backcrossing work was undertaken on an extensive scale (Table I). The results obtained show that success can be had in hybridization between the two groups of Asiatic and New World cottons. The F_1 hybrids have been successfully raised as also the backcrosses to New World cottons resulting in plants with some characters inherited from either group together with induced fertility.

All the hybrids and backcross plants are being maintained as ratoons. With a view to further propagation and maintenance, vegetative propagation by layering, cuttings, and grafting has been tried. Layering in unsuccessful while cuttings give varying success from 10 to 25 per cent. Grafting is very successful and a number of grafts have been secured by simple approach and bottle grafting methods.

Discussion

From the foregoing account of the work done at Surat and from reference to provious literature on the subject it can be said that :—

(1) It is possible to secure hybrids between the two groups of Asiatic and New World cottons differing in chromosome number.

(2) The fact that very few hybrids have been obtained by various workers, coupled with the similar experience at Surat, shows the difficulty involved but, as stated by Kanash, it can be safely concluded that to succeed in the attempt crossing must be resorted to on a large scale.

(3) All the F_1 hybrids reported above, have proved to be self-sterile. However, backcrossing to higher chromosome parent has been successful as shown by the experiments of Desai, Kanash, Harland, Nakatomi, Patel and the author at Surat. This is very encouraging as it indicates the way out of the impasse of sterility. So far, results of induced fertility by repeated backcrossing to higher chromosome parent have been reported only by Russian workers and by Harland.

(4) Percentage success in hybridization : It may be deduced from the previous literature as well as from the experience at Surat that success percentage is likely to vary from 0·01 to 2·5 in crosses between these two groups of Asiatic and New World cottons.

Thomson [1930] has summarized the literature as regards relative difference in success of reciprocal interspecific hybrids and concluded that more success is generally obtained when the species with the higher chromosome number is used as the female parent. In cottons, Zaitzev believed that better results could be obtained if the Asiatic types were used as the female parent. Kanash stated that reciprocal crossing is equally possible and successful. However, closer examination of his data indicates that the percentage success is greater when the species with the higher chromosome number is used as the female parent. Feng made a definite statement to the effect that whenever the female parent is the one with the higher number of chromosomes more success is obtained. The data presented here also confirm this conclusion.

In case of backcrossing a similar phenomenon is observed. Success has so far been obtained when the F_1 hybrid (which has higher chromosome number) has been used as the female parent. Again, of the two species entering into the cross, backcrosses are successful with higher chromosome parent as the

TABLE I

Results of hybridization between Asiatic and New World cottons and the F_1 hybrids backcrossed to the parents

Year	Parents	No. of flowers pollinated	No. of Bolls set	No. of seeds obtained	No. of hybrids obtained	Sucess per cent	Remarks
	Direct Crosses						
	♀ ♂						
1932-33	*G. hirsutum* × *G. herbaceum*	432	...	...	...	...	Desai's methods were tried
1933-34	*G. hirsutum* × *G. herbaceum*	1,924	...	...	...	...	
1934-35	*G. hirsutum* × *G. herbaceum*						
	Dharwar American × 1027 ALF	1,607	7	10	6	0·43	3 seeds failed to germinate. One hybrid died later.
	Punjab American × 1027 ALF				1		
	G. hirsutum × *G. arboreum*						
	Cambodia × Red Arboreum	742	2	4	4	0·53	Two hybrids died later.
	G. herbaceum × *G. barbadense*						
	1027 ALF × Exotic 1				1		
	G. herbaceum × *G. religiosum*	1,683	2	5		0·11	3 plants turned out to be like the mother parent
	1027 ALF × Exotic 2				1		
1935-36	*G. hirsutum* × *G. herbaceum*						
	Dharwar American × White Flower				2		
	Cambodia × 1027 ALF	1,244	21	22	1	0·64	14 seeds failed to germinate
	Punjab American + 1027 ALF				5		
	G. hirsutum × *G. arboreum*						
	Dharwar American × Gaorani 6	889	4	4	2	0·22	Two seeds failed to germinate
1936-37	*G. barbadense* × *G. herbaceum*						
	Maarad × 1027 ALF	792	2	3	3	0·37	
		...	...	...	23	...	Total F_1 hybrids on hand

TABLE 1—*contd.*

Year	Parents	No. of flowers pollinated	No. of bolls set	No. of seeds obtained	No. of hybrids obtained	Sucess per cent	Remarks
	Backcrosses						
1935-36	10 F_1 hybrids of 1934-35 × Respective New World parents	15,000	3	3	...	...	All failed to germinate
	10 F_1 hybrids of 1934-35 × Respective Asiatic parents	2,000	...	...	...	...	
	New World types × Hybrid pollen	6,716	...	...	...	...	
	Asiatic types × Hybrid pollen	500	...	...	...	...	
1936-37	20 F_1 hybrids of 1934-35 and 1935-36 × Respective New World parents	100,000	38	41	20	...	21 seeds failed to germinate. One plant died later, thus 19 backcross plants on hand
	New World types × Hybrid pollen	2,000	...	...	...	...	
	Asiatic types × Hybrid pollen	2,000	...	...	...	...	
1937-38	23 F_1 hybrids of 1934-35, 1935-36 and 1936-37 × Respective New World parents	196,000	47	51	15	...	36 seeds failed to germinate. 2 were damaged by insects and 5 died later, thus 8 backcross plants on hand
	Parentage of 27 successful backcross plants						
1	(*G. hirsutum* × *G. herbaceum*) F_1 × *G. hirsutum*						
	(*a*) (Dharwar American × 1027 ALF)F_1 × Dharwar American.	...	21				
	(*b*) (Cambodia × 1027 ALF) F_1 × Cambodia	...	2				
2	(*G. hirsutum* × *G. arboreum*) F_1 × *G. hirsutum*						
	(*a*) (Dharwar American × Gaorani 6) F_1 × Dharwar American.	...	2				
	(*b*) (Cambodia × Red Arboreum) F_1 × Cambodia	...	2				

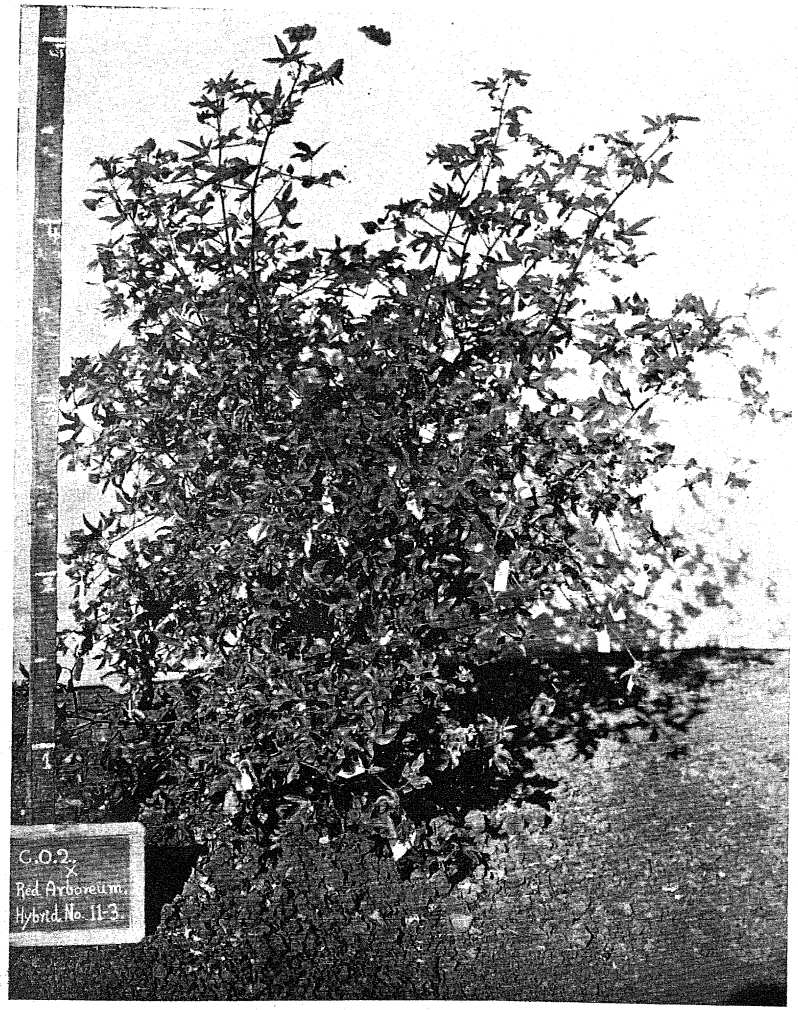


FIG. 1. *G. hirsutum* × *G. arboreum* F_1

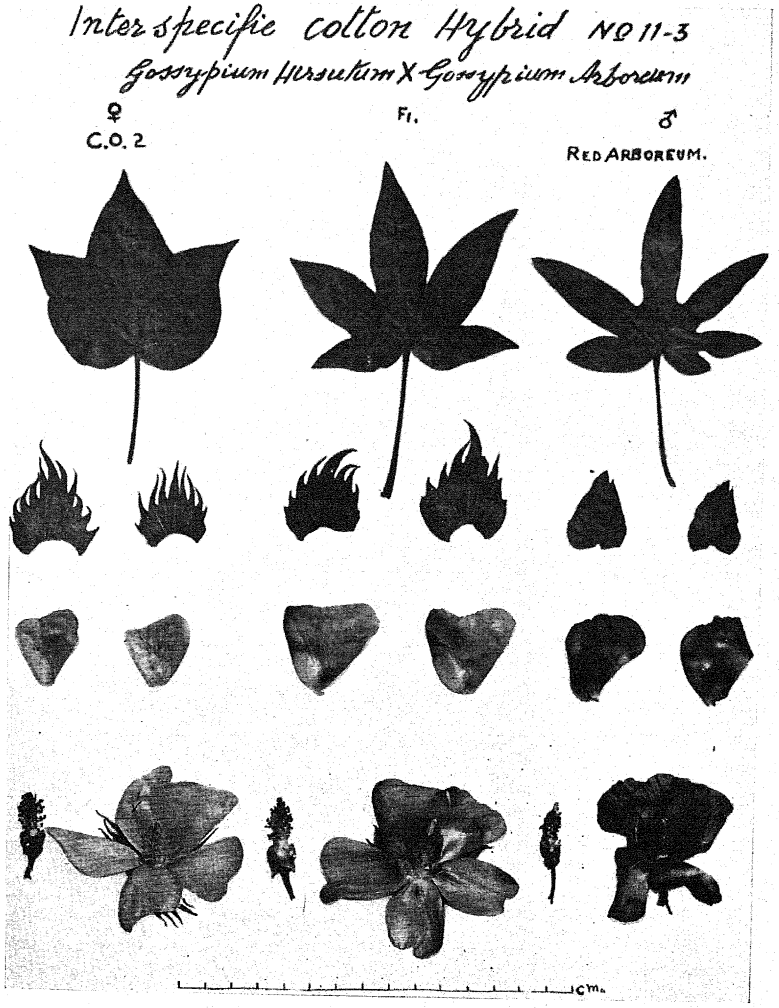


FIG. 2. Characters of the hybrid as compared to parents

pollen parent. Harland who was foremost in trying backcrossing on a large scale in interspecific hybrids, has shown that success is only obtained when pollen from a parent with higher number of chromosomes is used on to the flowers of the hybrid plants. Nakatomi and Kanash have obtained success in backcrossing when a male parent with higher number of chromosomes was used. It may be noted that in backcrossing, no success has yet been reported when Asiatics, or the species with the lesser number of chromosomes, is used as one of the parents.

(5) Size of bolls and number of seeds per boll in crosses : The peculiar phenomenon of the occurrence of only a few seeds per boll in case of crossed bolls in species crosses has been observed by various workers. Thirty-two seeds from twenty-one crossed bolls were obtained, the average number of seeds per boll coming to 1·52, thus confirming the observations of the various workers. In backcrossing, the formation of bolls on the F_1 hybrids shows a similar phenomenon. Only one seed per boll is the rule with few exceptions. The total number of bolls obtained from the F_1 hybrids in the three seasons was 88 giving 95 seeds.

(6) General characters of the F_1 hybrids :—

(*a*) *Hybrid vigour* : All the F_1 hybrids showed very marked hybrid vigour. They were more than three to four times the size of the parents (Plate IV).

(*b*) *Other characters* : In many characters, these hybrids are generally intermediate (Plate IV). The hairiness, shape of leaf, colour of petal, colour of pollen, etc., are all intermediate. The petal spot of Indian cottons is dominant but the intensity varies in different hybrids. There is a peculiar phenomenon in that the presence of various grades of spot, or even its complete absence, occurred on different branches of the same hybrid plant. Zaitzev noted a similar phenomenon in his hybrids. These variations of the different grades of spots, or their complete absence on different branches of the same plant, are such that by vegetative propagation of such branches plants showing these differences were raised. In case of Arboreum crosses, the anthocyanin pigmentation on plant body, leaf and flower is reduced. The flower colour is in accordance with Harland's description, viz. 'yellow with a red flush at the petal edges. Spot intermediate between the parents '.

(*c*) *Sterility* : As mentioned before all the hybrids proved completely self-sterile, except in so far as a few seeds could be procured by backcrossing with New World parents.

(7) Inducing fertility by backcrossing on F_1 hybrids : During the last three seasons, out of twenty-three F_1 hybrids, thirteen have set bolls on backcrossing with the New World cottons as pollen parents, and, as a result, twenty-seven backcrossed plants have been raised therefrom. The setting of bolls on backcrossing has been rare, but it is worth noting that one hybrid (Dharwar American × 1027 ALF) F_1—Hybrid No. 2-4 (which on cytological examination has been found to be a tetraploid)* has set a significantly large number of bolls consistantly during the last three seasons, the success percentage being

0·16, 0·49, and 0·21 for each of these seasons respectively. In fact, out of the twenty-seven backcross plants at present on hand, fifteen are derived from the tetraploid hybrid.

(8) Fertility in first backcross population : Of the twenty-seven plants grown, fifteen have set bolls on second backcrossing or selfing. Special mention may be made of a fully fertile plant No. 22 (Plate V). It has a red plant body and red flower colour with petal spot inherited from Asiatic parent. The character behaves as a simple dominant one as observed in the selfed and backcrossed progeny plants, with varying intensity of its expression. The progeny of first backcross plant No. 22 is fully fertile (Plate V). Normal setting of bolls also occurs by using this plant as a male or female parent in crosses with New World cottons. The fertility observed in most of the first backcrosses is encouraging in comparison with the results obtained by Harland who got full fertility after four backcrossings.

(9) There are many known physical and chemical treatments for getting fertility in interspecific hybrids by inducing doubling of chromosomes. Notable among these are, physical injury by wounding, ringing or callus formation, heat and cold treatment, X-ray applications, the use of chemicals, e.g. anæsthetics and narcotics such as chloroform and colchicine. Of these methods, wounding and ringing have been practised but without success. Trials were made at callus formation and though such is possible in cottons, sprouting of shoots from the callus did not take place. Anæsthetic like chloroform was also used but without success. The use of colchicine as an agent for inducing doubling of chromosomes appears to be promising, and experiments with it on cottons are being conducted by the author and results are awaited. If some such method proves successful, the question of inducing polyploids in cottons will be an easy task opening up a wide field for further research.

Summary

After summarizing the general position of interspecific hybridization in cottons, with references to the literature on the subject, details of similar work carried out at Surat for six seasons from 1932-38 are given.

In all, 23 F_1 hybrids between Asiatic and New World cottons have been grown. Backcrossing to New World cottons has proved successful and, as a result, twenty-seven first backcrosses have been obtained, many of which have also shown fertility through second backcrossing and selfing.

Data regarding the percentage success in hybridization, hybrid boll characters, general characters of the hybrids including sterility and fertility are discussed.

Acknowledgement

I am indebted to Mr M. L. Patel and Rao Saheb S. H. Prayag, the successive Cotton Breeders at Surat under whom this work was carried out, for their constant interest, advice and help, and in particular, to Rao Saheb Prayag

* 21 F_1 hybrids have been kindly examined cytologically by the Geneticist and Botanist, Institute of Plant Industry, Indore. All are triploids ($2n=39$) except two of which one is tetraploid ($2n=52$) and one pentaploid ($2n=65$).



FIG. 2. One of the selfed progeny plants of B C No. 22

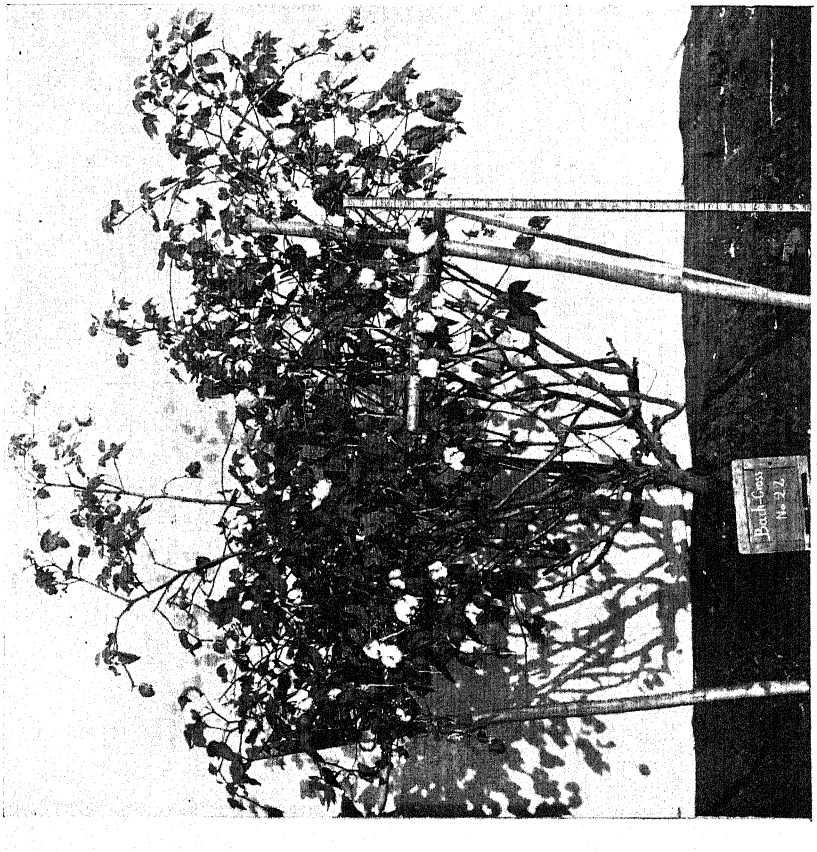


FIG. 1. Fertile first back cross progeny plant, B C No. 22 (Cambodia × Red Arboreum) F_1 × Cambodia



whose inspiration and assistance have been largely responsible for the production of this paper. I am also indebted to Mr G. B. Patel, Cotton Breeder, Viramgam, now at Surat, for assisting me in the preparation of the manuscript and in final drafting. Thanks are due to Messrs. B. J. Thakar, A. K. Shah, and P. S. Pandya, my colleagues, for the valuable help rendered in the course of the work.

Last but not the least, I am greatly indebted to Mr W. J. Jenkins, Director of Agriculture, Bombay Province, for sparing his valuable time in going through the paper and helping in bringing it to its present form.

REFERENCES

Amin, K. C. (1937). *Poona Agric. Coll. Mag.* **29**, 50-2
Desai, B. B. (1927). *Agric. J. Ind.* **22**. 351
Doak, C. C. (1934). *J. Hered.* **25**, 201-4
Feng, C. F. (1934). *P. B. Abs.* **7**, 2
——— (1935). *Bot. Gaz.* **96**, 485
Gammie, G. A. (1905). *The Indian Cottons*
Gates, R. R. (1938). *E. C. G. Rev.* **15**. 195-200
Harland, S. C. (1928). *Trop. Agric.* **5**. 116-7
——— (1932). *Nature* **129**, 398
——— (1935). *J. Genet.* **30**, 465-76
Kanash, S. C. (1932). *P. B. Abs.* **4**, 1 (full translation from P. B. B.).
Longley, A. E. (1933). *J. Agric. Res.* **46**, 217
Mell, P. H. (1897). *Alabama Agric. Expt. Sta. Bull.* **83**
Nakatomi, S. (1931). *Japan J. Bot.* **5**, 371
——— (1935). *Proc. Crop. Sci. Soc. Japan* **7**, 3-11
Patel, S. J. (1933). *Ind. J. Agric. Sci.* **3**, 127
Ramanathan, V. (1932). *Ann. Rep. Madras Agric. Dept.*
Skovsted (1934). *J. Genet.* **28**, 407-24
——— (1935). *J. Genet.* **30**, 447-63
——— (1937). *J. Genet.* **34**, 97-134
Szymanek (1936). *P. B. Abs.* **7**, 2
Thakar, B. J. and Amin, K. C. (1936). *Poona Agric. Col. Mag.* **28**, 19-20
Thompson, W. P. (1930). *Amer. Nat.* **64**, 405-21
Vycotski, K. (1930). *P. B. Abs.* **1**, 3
Watt, G. (1907). *The Wild and Cultivated Cotton Plants of the World*
Webber, J. M. (1935). *J. Agric. Res.* **51**, 1047-70
Zaitzev, G. S. (1922-23). *Agric. J. Ind.* **20**, 213 ; **21**, 460-70 ; **23**, 150-67 ; 261-8

GENETICAL STUDIES IN *COFFEA ARABICA* L.

A PRELIMINARY STUDY WITH YOUNG LEAF COLOUR AND RIPE PERICARP COLOUR

BY

R. L. NARASIMHA SWAMY, M.Sc.

(Received for publication on 27 July 1939).

INTRODUCTION AND HISTORICAL

THE colour of young leaves and the colour of pericarp of ripe fruits of *Coffea arabica* L. show well-marked differences. Sometimes varieties and strains have been distinguished by these characters. Taschdjian [1932] reports that *Café Bourbon* is 'to be distiuguished by the light green colour of the young leaves in contrast to the reddish to bronze of those of *Café Nacional.*' Krug [1935] mentions, "*Como é do conhecimento dos que trabalham com a Botanica do cafeeiro, constatam-se as seguintes cores nos brotos do cafeeiro : a* verde (*com diversas tonalidades desde* verde *quasi branco a* um verde *escuro*), *cue caracteriza os representantes typicos das variedades Mokka, Laurina, Murta e Bourbon ; b) bronze* (*de bronze claro até muito escuro*) *encontrado, de preferencia, nas variedades arabica typica* (*Nacional incluindo a forma aqui chamada de café Sumatra*) *e amarella* (*Amarello de Botucatu*) *e, finalmente, c) purpureo caracteristica da variedade purpurascens 'Café Roxo'.*" About the colour of pericarp of ripe fruits Krug [1936] mentions, '*Com relacáo car dos fructos presentmente nada podemos adeantar como, e sabido, a cor vermelha é a mais commum sendoa amarella caracteristica da var Amarella. (Amarello de Botucatu) é das variedades* (?) *Maragogipe é Bourbon Amarellos. A variedade Purpurascens caracteriza-se por fructos tambem arroxeados.*'

Recently, genetical work has been carried on using the colour of young leaves and the colour of pericarp of ripe fruits as characters for the study of inheritance in coffee. Krug [1936] mentions that controlled pollination has shewn a number of the plants selfed to be heterozygous. Bronze colour of the young leaves was dominant (though incompletely) to green ; both these were dominant to purple. Stoffels [1936] describes the 'behaviour of two groups of *arabica* coffee, one with brown leafed terminal shoots BB and the other with green, BV..... The effect of the environment on variation was very marked but the BB group proved much more adaptable than the BV group and less susceptible to dieback and black tip and to over production.

'Most of the BB strains tested were homozygous with regard to the colour of their terminal shoots but in some cases, although the numbers were too small for certainty, there were indications of a monohybrid ratio for the characters BB and BV. Which character was dominant depended on the mother plant.' He reports again, 'It was observed that the progeny of the so-called local varieties were some (BB) and some (BV) while those of the introduced coffees were all (BB).' [Stoffels, 1937].

Dealing with fruit colour Taschdjian [1932] mentions, ' The results of the cross *D'Utra* × *Amarello* indicate that the yellow colour is dominant to red.'

Coffea arabica L. is not the only species in which the pigmentation of the leaves has been made use of for genetical study. Lewis and Crane [1938] have investigated the anthocyanin pigmentation of leaves and shoots of apples. They mention, ' The anthocyanin coloration is a convenient character for genetic study, as it develops in the early seedling stage and the plants can be scored and the majority discarded while quite small, thus obviating the labour and expense of growing trees to maturity.' This fact may also be made use of with coffee.

Material and methods

A large number of varieties and strains of *Coffea arabica* L. has been collected and plants have been raised from these at the Government Coffee Experiment Station, Balehonnur. Several mother plants were selected from among these. For progeny tests seeds were obtained from the mother plants by controlled self-pollination. The seedlings raised have been planted in the field. The progeny of each mother plant is numbered. Thus, family 288 is the progeny of the mother plant S. 26. The mother plants and selections in their progeny have been crossed with pollen from Kent and Coorg strains of *arabica* coffee. These several families as well as the different strains and varieties formed the material for observation.

The characters studied were colour of young leaves and colour of pericarp of ripe fruits. The colour of young leaves that have just unfolded from the leaf bud was studied as, during the attainment of maturity the different colours change to the normal green colour. In the text wherever the colour of leaves is mentioned it refers to the colour of young leaves that have just unfolded from the leaf bud.

Three groups have been distinguished for the colour of young leaves viz. copper, brown, and light green. These appear to correspond with purple, bronze, and green colours of new leaves in Fig. 3 of Krug [1936].

While in the light green colour group the colour of leaves is uniform the same cannot be said of leaves in the copper and brown groups. Within the copper and brown classes the amount of coloration varies from only a slight tinge of copper red or brown to intense copper red or brown. There is no difficulty, however, in distinguishing the two groups. In this paper only the three broad classes—copper, brown, and light green—have been distinguished.

Pericarp colour of ripe fruits falls into two groups, viz. red and golden-yellow. These appear to correspond with red and yellow colours of fruits in Fig. 4 of Krug [1936].

Description

Kent's strain of *arabica* coffee has young leaves with copper colour. A major portion of cultivated coffee on the Station—Coorg strain—has copper leaves, a minority having brown leaves. Both the strains produce fruits with red pericarp. Golden Drop coffee—known as Amarella in Brazil [Cramer, 1913]—is characterized by light green leaves and fruits with golden-yellow

pericarp. Interspersed among the cultivated coffee wherein supply-planting has been carried on for some time, are a number of plants that have light green leaves and golden-yellow pericarp. All the observations I have made so far indicate that plants with copper and brown leaves have red pericarp, and, plants with light green leaves have golden-yelow pericarp.

TABLE I

Segregation in 1st and 2nd generation progeny of mother plants

Mother plant	Progeny Family No.	Colour of leaves of mother plant	Colour of pericarp of mother plant	Colour of leaves of progeny No. of plants with			Colour of pericarp of progeny No. of plants with	
				Copper	Brown	Light green	Red	Golden-yellow
S 26	288	Brown	Red	24	34	13	58	13
S 26	526	"	"	22	33	14	...	...
288-5	498	"	"	21	4	14	...	...
288-20	467	"	"	12	33	30	45	30
288-20	527	"	"	22	36	27	...	...
288-40	497	"	"	16	19	8	...	...
288-22	496	Copper	"	8	7	0	...	...
288-22	529	"	"	18	15	0	...	...
288-23	468	"	"	179	59	0	238	0
288-70	495	"	"	50	23	0	...	...
288-53	466	Light green	Golden-yellow	0	0	12	...	...
288-53	500	"	"	0	0	16	...	...
288-53	531	"	"	0	0	57	...	...
S 32	350	Brown	Red	15	18	14	33	14
S 48	360	"	"	7	23	0	30	0
S 13	356	Light green	Golden-yellow	0	7	24	7	24
S 63	375	"	"	0	72	32	72	32
S 44	353	Copper	Red	237	64	0	301	0
353-53	535	"	"	26	0	0	...	...
S 59	371	"	"	43	23	0	66	0
Kent	446	"	"	100	0	0	100	...
446-11	578	"	"	128	0	0	...	...
Kent	450	"	"	100	0	0	100	0
450-26	579	"	"	64	0	0	...	...
Kent	451	"	"	100	0	0	100	0

N.B.—The blanks in the last two columns indicate that the plants in those families have not fruited.

First generation progeny of three Kent and second generation progeny of two Kent plants have bred true for copper leaves. S 44 and S 59 have segregated in their first generation wherein, the plants have copper and brown

leaves. Second generation progeny of S 44 obtained from selfing one plant with copper leaves in the first generation, have only copper leaves.

In its first generation S 26 has segregated : there are plants with copper, brown, and light green leaves. Second generation progeny from selfing three plants with copper leaves in the first generation, have copper and brown leaves ; second generation progeny from selfing three plants with brown leaves in the first generation, have copper, brown, and light green leaves ; while, three families from selfing one plant with light green leaves in the first generation, have all light green leaves.

S 32 and S 48 have segregated in their first generation : progeny of S 32 have copper, brown, and light green leaves ; and, the progeny of S 48 have copper and brown leaves only.

The first generation progeny of S 13 and S 63 have brown and light green leaves.

TABLE II

Results of crossing mother plants and their progeny with Kent and Coorg strains

Parents	Family No.	Colour of leaves of parents		Colour of pericarp of parents		Colour of leaves of F_1 Hybrids. No. of plants with			Colour of pericarp of F_1 Hybrids. No. of plants with	
		Female parent	Male parent	Female parent	Male parent	Copper	Brown	Light green	Red	Golden-yellow
S 44 ♀ × Kent ♂ .	351	Copper	Copper	Red	Red	112	0	0	112	0
S 44 ♀ × Coorg ♂ .	352	,,	,,	,,	,,	79	0	0	79	0
S 26 ♀ × Kent ♂ .	327	Brown	,,	,,	,,	145	133	12	278	*2
S 26 ♀ × 286-14 (Kent)	490	,,	,,	,,	,,	72	32	1	104	...
S 26 ♀ × Coorg .	516	,,	,,	,,	,,	46	22	0	...	...
288-20 ♀ × 286-14 ♂ (Kent)	493	,,	,,	,,	,,	32	11	0	43	0
288-20 ♀ × Coorg ♂ .	518	,,	,,	,,	,,	125	72	0	...	...
288-53 ♀ × 446-11 ♂ (Kent)	569	Light green	,,	Golden yellow	,,	110	29	0	...	...
446-11 ♀ × 288-53 ♂ (Kent)	571	Copper	Light green	Red	Golden yellow	96	34	0	...	...
S 48 ♀ × Kent ♂ . .	395	Brown	Copper	,,	Red	88	14	0	102	0

N.B.—The blanks in the last two columns indicate that the plants in the families have not fruited.

* Of the 12 plants with light green leaves in the family only two have fruited.

S 44 has been crossed with pollen from a Kent and a Coorg plant. The F_1 hybrids have all copper leaves.

On crossing S 26 with pollen from two Kent plants the F_1 hybrids obtained have copper, brown, and light green leaves ; while, crossing S 26 with opllen from a Coorg plant the F_1 hybrids have copper and brown leaves only. One plant with brown leaves in the first generation progeny of S 26 has been crossed with pollen from a Kent and a Coorg plant. The F_1 progeny have copper and brown leaves.

The F_1 plants from the cross S 48 × Kent have copper and brown leaves.

One plant with light green leaves in the first generation progeny of S 26 has been crossed reciprocally with a Kent. In both the crosses the F_1 hybrids have copper and brown leaves.

TABLE III

Reciprocal intercrosses in the first generation progeny of S 26

Parents	Family No.	Colour of leaves of parents		Colour of leaves of F_1 hybrids No. of plants with		
		Female parent	Male parent	Copper	Brown	Light green
288-20 ♀ × 288-53 ♂ .	562	Brown . .	Light green .	14	16	38
288-53 ♀ × 288-20 ♂ .	566	Light green .	Brown . .	12	53	96
288-23 ♀ × 288-53 ♂ .	564	Copper . .	Light green .	37	37	15
288-53 ♀ × 288-23 ♂ .	567	Light green .	Copper . .	92	70	6

N.B.—The plants in the families have not fruited.

When plants with brown and light green leaves in the first generation progeny of S 26 are reciprocally crossed the F_1 progeny have copper, brown, and light green leaves. The plants with light green leaves are in excess. On crossing reciprocally plants with copper and light green leaves in the first generation progeny of S 26, the F_1 hybrids have copper, brown, and light green leaves. The plants with light green leaves are in a minority.

DISCUSSION

Krug [1935] reports, '*Constataram-se as seguintes condicoes de dominancia : Bronze e, incompletamente dominante sobre* verde, *sobre os hybridos* (F_1) *de coloracao intermediaria. Quanto ao purpureo, constatou-se que esta coloracao e recessiva tanto em relacao com o* verde, *como com o* bronze. *Somente a segunda geracaofilial* (F_2) *e os* ' back crosses ' *poderao revelar o numero de gens que condicionam a cor nas folhas novas.*' In a later publication he mentions [Krug, 1936], '*Nas variedades de cafe cultivades sao duas as cores predominantes das folhas novas :* bronze *e* verde *; trata-se, provavelmente, de um unico par de factores* (Br-Br, br-br) *apresentando o heterozygo to* Br-br. *dominantcia incompleta de Br, pois e bronze claro. A variedade Purpurascens possue folhas novas purpureas ; hybridos desta variedade com cafeeiros de folhas novas* verdes *ou bronzeadas apresentam dominancia completa destas duas cores sobre o purpurascens ; nada podemos, no emtanto, adeantar sobre si todos estes factores sao allelemorphos ou si o Br e o br sao epistaticos sobre um outro factor independente que determina a cor purpures*'.

Stoffels [1936] reports that Most of the BB strains tested were homozygous with regard to the colour of their terminal shoots but in some cases, although the numbers were too small for certainty, there were indications of a monohybrid ratio for the characters BB and BV. Which character was

dominant depended on the mother plant.' Again, 'Eight introduced varieties and 26 out of 33 lines of local varieties proved to be homozygous with regard to this colour character as well as to other morphological characters associated with leaves, stems and internodes. Seven lines of Mibirizi, on the other hand, showed a 3 : 1 segregation for leaf colour in the F_2 progeny, but whether BB or BV was dominant depended on whether the mother tree was BB or BV.' [Stoffels, 1936].

(*a*) *Leaf colour : segregation in first and second generation progeny*

(1) *Copper colour.*—Kent's strain appears to be homozygous for copper leaves : the first and second generation progeny have bred true for copper leaves. S 44, S 59, and plants with copper leaves in the first generation progeny of S 26, suggest the dominance of copper colour over brown in their progeny. In family 468 the segregation into copper and brown classes is in accordance with a 3 : 1 ratio ; whereas, in families 353, 495, and 371 the segregation is not inconsistent with a 3 : 1 ratio. The remaining two families—496 and 529—are very small. Thus, there appears to be a single factor difference between copper and brown classes.

(2) *Brown colour.*—S 26, S 32, and plants with brown leaves in the first generation progeny of S 26, segregate in their progeny which have copper, brown, and light green leaves. The segregation of S 26 is not inconsistent with a 1 : 2 : 1 ratio between copper, brown, and light green classes ; whereas, with the remaining families there is no such clear cut segregation. The progeny of S 48 have only copper and brown leaves ; but, the family is too small to be relied upon. The data so far obtained indicate that plants with brown leaves are heterozygous.

(3) *Light green leaves.*—S 13 and S 63 segregate differently in their progeny. The segregation into brown and light green classes in the progeny of S 63 is not inconsistent with a monohybrid ratio. However, the presence of excess of plants in the brown group in the progeny of S 63 is reversed in the progeny of S 13. S 13 and S 63 are two examples of the dominance of light green over brown leaves.

The plant with light green leaves in the first generation progeny of S 26 appears to be homozygous for leaf colour as its progeny breed true for the character.

(*b*) *Leaf colour in crosses*

(1) *Copper colour.*—The F_1 hybrids of the crosses S 44 × Kent and Coorg have all copper leaves. The F_1 progeny of the reciprocal crosses of a Kent and a light green leaved plant in the first generation progeny of S 26, have copper and brown leaves the former being in excess. These reciprocal crosses are of particular interest : both the parent plants are homozygous for leaf colour. In the F_1 progeny the copper colour of Kent dominates over the light green colour in producing an excess of plants with copper leaves ; and, also, the copper colour of Kent combines with the light green colour in producing a minority of plants with brown colour.

The F_1 hybrids of the reciprocal crosses between a plant with copper leaves and a plant with light green leaves in the first generation progeny of S 26 have copper, brown, and light green leaves, plants with copper leaves

being in excess. The copper leaved parent is not pure but, contains factors for brown colour and, hence, the presence of plants with green colour in the crosses is not unexpected. However, the presence of plants with copper leaves in excess in the crosses is suggestive of the dominance of copper over light green.

(2) *Brown colour.*—In the F_1 hybrids of the crosses between plants with brown and copper leaves, plants with copper leaves are in excess. In two of the crosses between S 26 and Kent, there are present a few plants with light green leaves. In these crosses there is a suggestion of the dominance of copper over brown.

The reciprocal crosses between 288-20 and 288-53 have F_1 hybrids with copper, brown, and light green leaves, the last one being in excess. As 288-20 produces a great percentage of plants with light green leaves in its progeny the presence of an excess of plants with light green leaves in the reciprocal crosses between 288-20 and 288-53 is according to expectation.

(c) *Colour of pericarp of ripe fruits.*

Pericarp colour appears to be linked up with leaf colour: all the observations so far made show that red pericarp is linked up with copper and brown leaves, and golden-yellow pericarp is linked up with light green leaves. Therefore, the segregation of pericarp colour follows closely the segregation of leaf colour in the several progeny.

Conclusion

Tests on mixing solutions of intense red and light green colours have resulted in brown colour. On crossing plants that are homozygous for copper and light green leaves, the F_1 hybrids have some plants with brown leaves Further, plants with brown leaves segregate in their selfed progeny into copper, brown, and light green classes. These facts indicate that brown leaves might be in the nature of a blend between copper and light green leaves.

The segregation in the progeny of plants with copper leaves into copper and brown classes is suggestive of a single factor difference between the two classes. Likewise, the segregation in the progeny of S 26 into copper, brown, and light green classes, and the segregation into brown and light green classes in the progeny of S 63, appear to be not inconsistent with a monohybrid ratio. Further, there are indications that copper leaves dominate over light green leaves and brown leaves ; and, light green leaves dominate over brown leaves.

Plants have been met with that are homozygous for copper and light green leaves. All the plants with brown leaves appear to be heterozygous.

The pericarp colour of ripe fruits appears to be linked up with leaf colour : red pericarp being characteristic of plants with copper and brown leaves ; and, golden-yellow pericarp characterizes plants with light green leaves.

Summary

(1) Colour of young leaves of *Coffea arabica* L. that have just unfolded from the leaf-bud, as well as, the colour of pericarp of ripe fruits show well marked variations. The young leaves have copper, brown, or light green colours ; the pericarp has either red or golden-yellow colour. These characters have been made use of for genetical study.

(2) Colour of pericarp of ripe fruits appears to be linked with leaf colour : plants with copper and brown leaves have red pericarp ; and, plants with light green leaves have golden-yellow pericarp.

(3) Plants homozygous for copper and light green leaves have been met with ; whereas, all the plants with brown leaves appear to be heterozygous.

(4) Copper colour of leaves combining with light green colour in the crosses between the two have produced some plants with brown leaves.

(5) Segregation in the progeny of plants with (*a*) copper and, (*b*) light green leaves into (*a*) copper and brown classes, and, (*b*) brown and light green classes respectively, seems to be not inconsistent with a monohybrid ratio. Segregation into copper, brown, and light green classes in the progeny of plants with brown leaves does not appear to be so clear cut.

(6) Copper leaves appear to dominate over light green and brown leaves ; and, light green leaves appear to dominate over brown leaves.

REFERENCES

Cramer, P. J. S. (1913). *' Gegevens Over De Variabilitat Van De In Nederlandsch—Indië, Verbouwde Koffie = soorten. Batavia.* 207

Krug, C. A. (1935). *Instituto Agronomico De Campinas. Relatorio De 1935.* **1**. *Sao Paulo—Brasil.* 12

Krug, C. A. (1936). *Genetica de Coffea. Instituto Agronomico De Campinas Boletim Technico* **26**, 14

Lewis, D, and Crane, M. B. (1938). *J. Gen.* **37**, 119-28

*Stoffels, E. (1936). *Publ. Inst. Agron. Congo Belge : Ser. Sci. No.* **11**, 41.

*Stoffels, E. (1937). *Journees Agron. Colon. Gembloux* 129-33

*Taschdjian, E. (1932). *Z. Züchtung.* : A **17**, 341-54

*Abstracts in *Pl. Br. Abs.* of Imp. Bureau of Pl. Br. & Gen. and, in *Hort. Abs.* of Imp. Bureau of Hort. and Plantation Crops were referred to.

INSECT POLLINATORS OF *TORIA* (*BRASSICA NAPUS* LINN., VAR. *DICHOTOMA* PRAIN), AND *SARSON* (*B. CAMPESTRIS* LINN., VAR. *SARSON* PRAIN) AT LYALLPUR

BY

KHAN A. RAHMAN, B.Sc. (EDIN.), PH.D. (CANTAB.), F. R. E. S.

Entomologist to Government, Punjab, Agricultural College, Lyallpur

(Received for publication on 2 November 1939)

INTRODUCTION

A number of economic plants (e.g. red clover, Cucurbitaceæ, some of the Brassicæ, apple, etc.) depend entirely upon insects for pollination [Waite, 1895, '99; Treherne 1923; Williams, 1925]. An increase in the population of such insects results in a material increase in the yield of the crop [Alderman, 1918; Auchter, 1922; Farrar, 1931].

In India this fruitful line of investigation has remained practically untouched. Apart from Burkill's random notes [1906-09, 1911], Ali Mohd. *et al's* [1931] and Ali Mohd.'s [1935] articles are the only contributions to the subject. The reason for this neglect is not far to seek. Economic Entomologists have been, and are still, busy combating injurious insects to realize the full significance of this branch of their subject, the importance of which to a pre-eminently Agricultural country like India, cannot be over-emphasized. It is, therefore, reasonable to maintain that a more intimate and comprehensive knowledge of insect visitors to the flowers of our plants of economic importance is long overdue.

OBJECTS OF THE PRESENT INVESTIGATION

Apropos of the record low yield of *toria* during 1928-29 in the Punjab Afzal Husain [1930] made the following observation: 'The last *toria* crop failed, and it was noticed that although the number of pods per plant was fairly large, the number of seeds per pod was very little, which shows defective pollination. As this crop is pollinated by insects, it seems likely that on account of certain unknown causes insects pollinating *toria* were not present in large numbers. It is a well known fact that insect pollinators play a most important part in the economy of nature and the question is so important that it cannot be ignored much longer.'

The work on insect visitors to *toria* and *sarson* flowers was, therefore, begun in January, 1930, at Lyallpur with a view to determine: (1) the species of insect visitors and their importance as pollinating agents, and (2) the relative significance of the important pollinators. This information was considered an essential preliminary for the elucidation of those 'unknown causes' which retard insect activity.

THE SPECIES OF INSECT VISITORS TO *TORIA* AND SARSON FLOWERS AND THEIR IMPORTANCE AS POLLINATORS.

Method of study.—The insect visitors to *toria* and *sarson* flowers were collected* for about 131 days i.e. from November to February, 1930 and 1931, in the Botanical Experimental Farm, Lyallpur. Collections were started almost immediately after the flowers appeared and were usually made between 12 noon to 3 P.M.—the period of greatest insect activity—for an average of 2·17 hours a day.

Weather conditions during collection period.—Excepting eight days†, when the prevailing weather conditions were not favourable, the remaining 123 days, particularly during the collection period, had ideal conditions for insect flight and activity. Table I gives the meteorological data which was found favourable for insect flight during *toria* and *sarson* seasons in 1930 and 1931.

Insect visitors.—The collections made include 105 different species representing 55 families of 9 orders of the Class Insecta. The importance of these insects as pollinating agents is discussed below.

ORDER HYMENOPTERA

Fam. APIDAE.—*Apis florea* Fab. is the only representative of this family secured from *toria* and *sarson* flowers. Table II gives the numbers collected from the two crops during the specified weeks.

It is seen from the above table that *Apis florea* Fab. is slightly more abundant in *sarson* than *toria*. It begins to desert this crop for other flowers towards the end of February.

The nesting habits of *Apis florea* Fab. are described by Ghosh [1915].

This bee works zealously and enthusiastically ' during bright, sunny, warm weather ', when there is slight or no wind. During inclement weather it does not leave its hive. When overtaken by bad weather during work it immediately suspends its activities and clings to the flower. In this condition it allows itself to be picked up by hand without stinging.

Apis florea Fab. works in a purposeful manner. Table III gives the number of flowers visited per minute.

Thus during favourable weather *Apis florea*, Fab., on an average, visits six flowers per minute.

Its *modus operandi* on flowers is ideal for cross-pollination. Alighting on a flower it sends its proboscis down immediately to a nectary and in consequence the head comes in contact with anthers and gets heavily dusted with pollen. The next nectary is reached with the body usually lying across the anthers. Much more frequently, however, the bee lies across the apex of the stigma to lap up nectar : it is this posture that results in pollination.

* The collections were made by Messrs. K. G. Bhandari, B. Singh, R. Takoo, N. Kishore, the late S. Datt, Sana Ullah and the author.

† 12th and 24th January, 1930.
27th February, 1930.
24th November ,1930.
7th and 10th February, 1931.

TABLE I

Showing meteorological data favourable for insect flight during toria *and* sarson *seasons in 1930 and 1931 respectively*

Month and year	Flowering period of	Dates	Collection made for		Mean maximum temperature (F)	Mean minimum temperature (F)	Mean humidity per cent	Amount of sun-shine		Amount of rain-fall (inches)	Wind velocity	
			Hrs.	Mts.				Hrs.	Mts.		Maximum Miles	Minimum per hour
November 1930	*toria*	19-25	15	..	77·85	48·28	66·71	50	30	..	2	1
December 1930	*toria*	1-7	13	..	78·14	45·28	60·71	44	30	..	2	1
January 1930	*sarson*	13-19	16	30	62·85	36·28	81·28	..	..	·7	3	1
February 1930	*sarson*	13-19	6	..	78·00	47·43	72·42	..	..	..	2	1
November 1931	*toria*	11-17	12	..	82·42	49·00	53·42	62	25	..	3	1
December 1931	*toria*	7-13	14	..	73·28	43·28	73·28	53	15	..	3	1
January 1931	*sarson*	24-30	12	30	66·28	38·14	72·00	47	48	..	3	1
February 1931	*sarson*	13-19	10	..	67·42	41·85	74·14	44	42	..	3	1

TABLE II

Showing numbers of Apis florea *Fab. collected from* toria *and* sarson *during 1930 and 1931*

Name	1930		1931	
	toria (November 19-25 December 1-7)	*sarson* (January 13-19 February 13-19)	*toria* (November 11-17 December 7-13)	*sarson* (January 24-30 February 13-19)
Apis florea Fab. . . .	62	188	216	370

TABLE III

Showing number of sarson *flowers visited per minute by* Apis florea *Fab.*

Date	Time of observation		Duration of observation (minutes)	Total number of flowers visited	Number of flowers visited in one minute
	From P.M.	To P.M.			
19-1-30	12·1	12·7	6	30	5
19-1-30	1·5	1·6	1	8	8
19-1-30	2·29	2·32	3	22	7·3
8-2-30	2·34	2·39	5	37	7·4
14-2-30	2·42	2·47	5	25	5
26-1-31	2·52	2·54	2	10	5
9-2-31	2·53	2·55	2	16	8
12-2-31	2·58	3·9	11	45	4
14-2-31	2·41	2·49	8	41	5·1

Fam. ANDRENIDÆ.—This family was strongly represented. Table IV gives the names and numbers of the members of this family collected from *toria* and *sarson* during the specified weeks.

It is seen from Table IV that *Andrena ilerda* Cam. and *Halictus* sp. are more abundant in *sarson* and *toria* crops than any other species of *Andrenidæ*. Both these solitary bees are exceedingly industrious and work in a purposeful manner. Because of these qualities and their numbers and body structure these bees are among the most important pollinators of flowers. Their *modus operandi* on flowers is identical with that of *Apis florea* Fab.

At Lyallpur *Andrena ilerda* Cam. begins to visit *toria* flowers in the second week of November. It reaches its maximum numbers in December : in fact it is during this month that it predominates over all other insect visitors. It constructs its nest in and around *toria* fields. For this purpose it makes a 22 in.—25 in. long tunnel with a number of side tunnels along its course.

In the case of an allied species each side of tunnel is said to terminate in a cell in which balls of ' bee-bread ' (for egg-laying) are stored.

TABLE IV

Showing names and numbers of Andrenidæ collected from toria *and* sarson *during 1930 and 1931*

Name	1930		1931	
	toria (November 19-25 December 1-7)	*sarson* (January 13-19 February 13-19)	*toria* (November 11-17 December 7-13)	*sarson* (January 24-30 February 13-19)
Andrena ilerda Cam.	299	25	384	23
Halictus sp.	22	51	112	46
A. lecena Cam.	8	3	..	10
A. satellita Nurse	..	3	..	17
Halictus salsettensis Ckll.	..	2	..	14
Andrena sp.	1	2	2	2
Andrena sp.	3	1	2	2
A. ephippium Spin. var. *dilecta Mocs.*	..	2	..	..
A. fulvicrus Kirby	..	..	..	2

Six observations were made to study the duration of a pollen-collecting trip. The method adopted was to keep a watch over the burrow from which an *Andrena ilerda* Cam. was seen coming out. (In all observations the burrow entrance was blocked with a clod which was removed when the insect returned).

It will be observed from Table V that the first visit of *Andrena ilerda* Cam. (apart from the first forced return in observation II) lasted for 3 to 4½ hours. The material collected during this trip required 7-10 minutes to be unloaded. The second visit lasted for about 1½ to 2½ hours, the insect taking 2-4 minutes to unload. The third visit was of the shortest duration for it lasted only from 19 minutes to 1½ hours. For pollination the first visit, and to a lesser degree the second visit, are most important, because ' an examination of the anthers of the freshly opened flowers at about 3 P.M. showed them to be absolutely devoid of pollen grains which are evidently carried away by their insect visitors ' [Ali Mohd. *et al*, 1931].

TABLE V

Showing numbers and duration of pollen-collecting trip of Andrena ilerda *Cam. during favourable weather*

No. of observation	Date	Time		Duration of						Remarks.
		Left burrow	Returned to burrow	First visit		Second visit		Third visit		
				hrs.	mts.	hrs.	mts.	hrs.	mts.	
I	29-11-1930	10·13 A.M.	1·23 P.M.	3	10	..	..	..	..	Observation discontinued after 3-35 P.M.
		1·31 P.M.	3·35 P.M.	..	..	2	4	..	..	
II	1-12-1930	10·36 A.M.	12·13 P.M.	1	37	..	..	..	..	Returned at 12-13 being hotly persued by *Philanthus depredator*. Took shelter under a lump of earth and on removal of clod ran into the burrow.
		12·19 P.M.	1·45 P.M.	..	..	1	26	..	..	
		1·48 P.M.	..	..	..	..	..	..	..	Did not return up to 5-30 P.M. when observation was discontinued.
III	2-12-1939	10·9 A.M.	1·14 P.M.	3	5	..	..	..	..	Did not come out upto 5-30 P.M. when observation was discontinued.
		1·24 P.M.	3·46 P.M.	..	..	2	22	..	..	Caught in a tube placed at the entrance next day.
		3·50 P.M.	5·11 P.M.	..	..	..	..	1	21	
IV	8-12-1930	2·10 P.M.	4·49 P.M.	..	..	2	39	..	..	Observation discontinued after 4-49 P.M.
V	20-12-1930	10·19 A.M.	2·46 P.M.	4	27	..	..	..	..	Observation discontinued after 5-30 P.M. as the insect did not return.
		2·55 P.M.	4·48 P.M.	..	..	1	53	..	..	
		4·50 P.M.	5·0 P.M.	..	..	..	..	0	10	
VI	22-12-1930	3·6 P.M.	4·47 P.M.	..	..	1	41	..	..	Observation discontinued after 4-47 P.M.

Like *Apis florea* Fab. *Andrena ilerda* Cam. also works in a purposeful manner and table VI gives the number of flowers visited in one minute.

TABLE VI

Showing number of flowers visited per minute by Andrena ilerda *Cam.*

Date	Time of observation		Duration of observation (minutes)	Total number of flowers visited	Number of flowers visited in one minute
	From P. M.	To P. M.			
26-11-30	1·28	1·30	2	13	6·5
26-11-30	2·46	2·49	3	18	6
28-11-30	1·34	1·36	2	15	7·5
4-12-30	12·15	12·19	4	33	8.2
16-12-30	1·30	1.33	3	26	8·6
19-12-30	2·40	2·42	2	16	8
27-11-31	3·6	3·11	5	39	7.8
30-11-31	1·15	1·17	2	15	7·5
5-12-31	1·15	1·18	3	22	7·3
14-12-31	12·45	12·49	4	32	8

Thus during favourable weather *Andrena ilerda* Cam., on an average, visits 7·5 flowers per minute.

A. ilerda Cam. is the most important insect for *toria* pollination, but being wild it is not possible to do anything with it in a practical way to ensure its presence, or augment its numbers, in *toria* fields.

At Lyallpur the appearance of *Halictus* sp. in *toria* synchronizes with its (*toria*) flowering : it remains active in this crop until *sarson* flowers appear. Thus before the appearance of *Andrena ilerda* Cam. it plays the most important part in the pollination of *toria*.

In its nesting habits it resembles *Andrena ilerda* Cam. It lives in small colonies, each member occupying a cell which is joined to the main tunnel by a side branch.

Table VII gives the number of flowers visited by *Halictus* in one minute.

TABLE VII

Showing number of flowers visited per minute by Halictus *sp.*

Date	Time of observation		Duration of observation (minutes)	Total number of flowers visited	Number of flowers visited in one minute
	From P. M.	To P. M.			
17-1-30	12·0	12·8	8	20	2·5
26-1-30	2·58	3·3	5	18	3·6
19-2-30	2·10	2·14	4	14	3·5
22-2-30	1.25	1·28	3	17	5·6
16-11-31	1.30	1·34	4	13	3·2
20-11-31	1·46	1·49	3	7	2·3
30-11-31	2·11	2·17	6	23	3·8
11-12-31	2·1	2·3	2	8	4

Thus during favourable weather *Halictus* sp., on an average, visits 3·5 flowers per minute.

Fam. COLLETIDÆ.—*Colletes reticulata* (Cam.), *C. nursei* Cam., and *Colletes* sp. are the only representatives of these primitive bees which were taken from *sarson* flowers. Only six specimens were collected and this fact alone marks them out to be useless as pollinating agents.

Fam. XYLOCOPIDÆ.—*Xylocopa* (*Nyctomelita*) *nasalis nasalis* Westw. is the only representative of this family secured from *toria* and *sarson* flowers. It is a powerful flier producing a loud buzzing noise during flight. It is never abundant—only eight specimens were collected—and this fact alone rules it out from the list of useful pollinators.

Fam. CERATINIDÆ.—*Ceratina sexmaculata* Sm. is a casual visitor to *toria* and *sarson* flowers. It is a slow and lazy worker and its method of obtaining nectar is such that only the front of its head comes in contact with the anthers. It has no value as a pollinating agent.

Fam. NOMADIDÆ.—Of the three species collected *Nomada* 2 spp. are comparatively more abundant as is seen from the following table :—

TABLE VIII

Showing names and numbers of Nomadidæ collected from toria *and* sarson *during 1930 and 1931*

Name	1930		1931	
	toria (November 19-25 December 1-7)	*sarson* (January 13-19 February 13-19)	*toria* (November 11-17 December 7-13)	*sarson* (January 24-30 February 13-19)
Nomada 2 spp.	65	38	163	29
Crocisa ramosa Lep. ?	..	..	1	..

The general appearance of *Nomada* 2 spp. is suggestive of *Polistes hebræus* (Fab.)

During November and December, they were often seen at 8 A.M. suspended from leaves of *toria* by their mandibles. They are poor fliers and always fly low to the ground. They live as parasites in the nests of *Andrena* spp. and *Halictus* spp. for their larvæ are fed ' upon the provisions originally destined for the progeny of the host species ' [Imms, 1934]. They are, therefore, undesirable visitors to *toria* and *sarson* fields.

Fam. ANTHOPHORIDÆ.—*Anthophora vedetta* Nurse has the longest proboscis among the bees discussed in this paper. It prefers to feed in flowers where the nectaries are deep seated, e.g., ' *taramira* ' (*Eruca sativa*). It is, therefore, very rarely that one collects it from *sarson*.

Fam. BEMBECIDÆ.—*Bembex trepanda* Dahlb. is the only representative of this family taken from *toria* and *sarson* flowers.

It nests in the ground and shows parental care for its offspring. It preys upon Syrphidæ, Muscidæ and Calliphoridæ which it supplies daily to its larvæ. It is therefore an undesirable visitor to *toria* and *sarson* flowers.

Fam. LARIIDÆ.—*Liris hæmorrhoidalis* (Fab.) is the only representative of this family secured from *toria* flowers. It preys upon *Andrena ilerda* Cam. and other bees and is therefore an undesirable visitor to *toria* flowers.

Fam. PHILANTHIDÆ.—*Philanthus depredator* Smith is the only representative of this family secured from *toria* flowers.* Table IX gives the numbers of this insect collected from *toria* flowers during the specified weeks.

* It is in hibernation during the flowering period of *sarson*.

TABLE IX

Showing numbers of Philanthus depredator *Smith collected from* toria *during 1930 and 1931*

Name	1930	1931
	toria (November 19-25 December 1-7)	*toria* (November 11-17 December 7-13)
Philanthus depredator Smith	90	118

P. depredator Smith is a handsome and graceful insect. It constructs sinuous burrows in the soil. It closes the burrow entrance before going out to 'hunt'. This is done by shovelling back the soil particles with its legs 'in the manner of a dog digging'. On its return the prey is at first deposited on the ground near to the entrance hole which is then opened and the prey dragged into the burrow.

P. depredator Smith alternates its work of destruction with that of feeding on nectar. It is, however, a very slow and unsteady worker as is seen from Table X.

TABLE X

Showing number of flowers visited per minute by Philanthus depredator *Smith*

Date	Time of observation		Duration of observation (minutes)	Total number of flowers visited	Number of flowers visited in one minute
	From	To			
	P.M.	P.M.			
20-11-30	2·1	2·3	2	8	4
23-11-30	2·16	2·21	5	20	4
29-11-30	2·16	2·21	5	18	3·6
1-12-30	1·0	1·7	7	29	4·1
21-11-31	12·0	12·2	2	9	4·5
27-11-31	1·4	1·7	3	14	4·6
30-11-31	1·15	1·20	5	23	4·6

Thus, on an average, this insect visits about four flowers per minute.

Its main object in visiting *toria* flowers, however, is to prey upon *Andrena ilerda* Cam., and *Apis florea* (Fab.), etc. for provisioning its nest.

P. depredator Smith attacks a bee when it (bee) is busy collecting pollen and nectar, and on average takes 30 seconds (average of 12 observations) to paralyse it. Afterwards, it is 'carted' to the burrow in the usual Sphegid manner. Thus *P. depredator* Smith is the most unwelcome visitor to *toria* flowers.

Fam. VESPIDÆ.—Impregnated females of *Polistes hebræus* (Fab.) and *Vespa orientalis* * Linn. visit *toria* flowers during November and 1st week of December.

They are predaceous upon Apidæ and Andrenidæ: they feed upon their honey-stomachs which they obtain by biting off the thorax. They are thus undesirable visitors to *toria* flowers.

Fam. EUMENIDÆ.—Of the three species collected *Odynerus* sp. was comparatively more abundant as is seen from the following table:—

TABLE XI

Showing names and numbers of Eumenidæ collected from toria *and* sarson *during 1930 and 1931*

Name	1930		1931	
	toria (November 19-25 December 1-7)	*sarson* (January 13-19 February 13-19)	*toria* (November 11-17 December 7-13)	*sarson* (January 24-30 February 13-19)
Odynerus sp.	16	..	26	..
Eumenes dimidiatipennis Sauss.	..	..	2	..
Eumenes sp.	1	..	..	..

Odynerus sp. is a slenderly built insect. It visits *toria* flowers to feed on nectar and pollen. Because of its smooth body it is useless as a pollinating agent.

The female possesses a formidable sting. It is used to sting Lepidopterous larvæ into a state of torpor for storing them in a specially constructed earthen cell as food for its progeny.

Fam. SCOLIIDÆ.—*Campsomeris thoracicus* (Fab.), *C. thoracicus* var. *aureicollis* Lep. and *Scolia* sp. are the only representatives of this family secured from *toria* flowers. They are rapid fliers and are difficult to catch. During work they show a certain degree of persistency and fly rather than crawl,

* It is interesting to record here that on 22-11-31 at 3-14 P.M. a King crow (*Dicrurus macrocercus macrocercus* Vieill.) was observed to snap at and swallow three *Vespa orientalis* Linn. within five minutes.

from flower to flower. They obtain nectar like honey bees. But they are never abundant, therefore, their value as pollinating agents is limited.

Fam. CHRYSIDIDÆ.—Three specimens of *Chrysis indica* Macs. were collected from '*toria*' flowers. It has a brilliant metallic green colour and when disturbed it rolls itself quickly into a ball. It is a parasite of *Bembex*, *Odynerus* and *Eumenes*.

Fam. FORMICIDÆ.—Only two representatives, namely *Cataglyphis bicolor* subsp. *Setipes* (Forel), and *Messor barbarus* (Linn.) var. *instabilis* Sm. of this family were found visiting *toria* and *sarson* flowers to feed on nectar.

During feeding *C. bicolor* subsp. *Setipes* (Forel) introduces its head from between the floral 'claws' to reach the nectaries, the body sprawling over the adjacent flowers. When frightened it drops to the ground. Its body is smooth and unfit for the carriage of pollen.

Winged forms of *Messor barbarus* Linn. var. *instabilis* Sm. visit *toria* and *sarson* flowers but are never abundant. Their body being covered with hairs is very well suited for the carriage of pollen. Therefore, they cannot be entirely useless as pollinating agents.

Order DIPTERA

Fam. SYRPHIDÆ.—This family was strongly represented as is seen from the following table :—

TABLE XII

Showing names and numbers of Syrphidæ collected from toria *and* sarson *during 1930 and 1931*

Name	1930		1931	
	toria (November 19-25 December 1-7)	*sarson* (January 13-19 February 13-19)	*toria* (November 11-17 December 7-13)	*sarson* (January 24-30 February 13-19)
Eristalis tenax (Linn.)	28	66	19	74
E. quinquelineatus (Fab.)	10	13	18	8
E. æneus Scop.	8	7	11	2
E. tæniops Wied.	4	4	..	3
Sphærophoria indiana Big.	3	4	4	1
Syrphus balteatus (de Geer)	..	..	6	1
Lasiopticus albomaculatus Macq.	1	..	..	1
Ischiodon scutellaris (Fab.)	3	..	..	..

Eristalis tenax (Linn.) is a heavy bodied insect which bears a close resemblance to *Apis indica* Fab. During flight it produces a loud hum. It is a graceful insect to watch on the wing, but its movements on the flowers are awkward and clumsy. It is a spasmodic worker because 'hovering' over a flower and sitting and cleaning itself are as important to it as feeding.

Its *modus operandi* on a flower is identical with that of *Apis florea* Fab. described before. Its progress on flowers is very satisfactory as is seen from Table XIII.

TABLE XIII

Showing number of flowers visited per minute by Eristalis tenax *Linn.*

Date	Time of observation		Duration of observation (minutes)	Total number of flowers visited	Number of flowers visited per minute
	From	To			
	P.M.	P.M.			
18-1-30	3·5	3·12	7	47	6·7
25-1-30	2·7	2·10	3	18	6
7-2-30	1.38	1.49	11	97	8·8
19-11-30	12·10	12·18	8	49	6·1
	A.M.	A.M.			
8-12-30	11·4	11·8	4	39	9·7
	P.M.	P.M.			
13-12-30	1·58	2·1	3	26	8·6
11-2-30	1.15	1·18	3	15	5
	A.M.	A.M.			
11-11-31	10·9	10·15	6	35	5·8
24-11-31	11·11	11·20	9	60	6·6
	P.M.	P.M.			
7-12-31	1·5	1·10	5	34	6·8

Thus, on an average, it visits seven flowers per minute.

It is found in the fields from early morning to late afternoon and is met with in all types of weather. It is an important pollinator.

The other species of *Eristalis* though much less abundant are equally efficient as pollinating agents. *Sphœrophoria indiana* Big. is a small sized insect which hovers 'poised motionless' in the air over a flower before alighting. It is a spasmodic worker.

Lasiopticus albomaculatus Macq., *Ischiodon scutellaris* Fab., and *Syrphus balteatus* de G. are of little significance as pollinating agents. The larvæ of the last named, however, destroy the Mustard Aphis.

Fam. AGROMYZIDÆ.—*Phytomyza atricornis* Meig., a representative of this family, is a minute insect which is quite abundant towards the end of *sarson* season. When disturbed it shoots up in the air and looks like a dust particle.

It is found on the wing in the mornings, evenings and on cloudy days, but has never been observed visiting *sarson* flowers. When it is sunny and warm it takes shelter under cover of the leaves lying on the ground or other suitable shady places.

Its larvæ damage *sarson* leaves by making zigzag whitish galleries. When infestation is severe every leaf may be affected. The attacked leaf becomes distorted, turns yellow and ultimately falls down.

Fam. MUSCIDÆ.—Six species, namely, *Musca domestica nebulo vicina* Macq., *M. vitripennis* Meig., *M. domestica nebulo* Fab., together with three undetermined species of the genus *Musca* are the only representatives of this family secured from the flowers of the two crops.

Musca domestica nebulo vicina Macq. is an erratic and an unstable worker, and is not a persistent seeker of pollen and nectar. It also licks up stigmatic secretions. When feeding on nectar its body usually lies perpendicularly between the stalks of the stamens and the style of the stigma, but when licking up stigmatic secretions or feeding on pollen its body usually rests on petals. After every ' feed ' it may settle on the body of the observer, on bags, bamboos, plants, or on the ground, or may even engage in a playful ' combat ' with another ' fellow '. But it is found (along with other Muscids) in the fields from morning till late in the afternoon and is active both during fine and inclement weather. Therefore, it is safe to infer that Muscids in general and *Musca domestica nebulo vicina* Macq. in particular may play a minor part in pollination.

Fam. CALLIPHORIDÆ.—Of the six species of this family collected *Trichometallea pollinosa* Tns. was consistently more abundant as is seen from Table XIV.

TABLE XIV

Showing names and numbers of Calliphoridæ collected from toria *and* sarson *during 1930 and 1931*

Name	1930		1931	
	toria (November 19-25 December 1-7)	*sarson* (January 13-19 February 13-19)	*toria* (November 11-17 December 7-13)	*sarson* (January 24-30 February 13-19)
Trichometallea pollinosa Tns.	24	14	19	29
Rhinia discolor Fab.	4	3	29	6
Lucilia sericata Meig.	2	..	5	1
Calliphora erythrocephala Meig.	..	5	..	1
Sarcophaga sp.	..	..	5	..
Chrysomyia megacephala Fab.	1	..	..	..

Trichometallea pollinosa Tns. feeds on nectar and pollen as well as licks up stigmatic secretions. Its habits and mode of feeding resemble those of *Musca domestica nebulo vicina* Macq. When working seriously its rate of progress is fairly satisfactory (Table XV).

TABLE XV

Showing number of flowers visited per minute by Trichometallea pollinosa *Tns.*

Date	Time of observation		Duration of observation (minutes)	Total number of flowers visited	Number of flowers visited per minute
	From	To			
	A.M.	A.M.			
18-1-30	10·12	10·16	4	18	4·5
21-1-30	11·39	11·43	4	11	2·75
	P.M.	P.M.			
25-1-30	3.0	3·2	2	8	4
	A.M.	A.M.			
25-11-30	10.48	10·53	5	21	4·2
26-11-30	10·0	10·3	3	9	3
	P.M.	P.M.			
1-12-30	12·30	12·32	2	11	5·5
6-2-31	2.30	2·33	3	7	2·3
17-2-31	1·7	1·9	2	7	3·5
20-11-31	1·18	1·22	4	15	3·75
15-12-31	1·17	1·19	2	12	6

Thus it visits, on an average, 3·9 flowers per minute.

It is a fairly useful insect as a pollinating agent.

Rhinia discolor Fab. is about the size of a house-fly, but is darker in colour with whitish abdomen. It hovers over a flower like a Syrphid pinned to the spot: it may, however, dart to one side, disappear momentarily and then reappear about the same spot. During flight it produces a characteristic buzzing sound.

Its habits and mode of feeding resemble those of *T. pollinosa* Tns. Because of its numbers its value as a pollinating agent cannot be questioned.

L. sericata Meig., *C. erythrocephala* Meig., and *C. megacephala* Fab. are too few in *toria* and *sarson* flowers to be of any use as pollinating agents.

Fam. SEPSIDÆ.—Of the two species collected, *Sepsis* sp. was commoner as is seen from Table XVI.

TABLE XVI

Showing names and numbers of Sepsidæ collected from toria *and* sarson *flowers during 1930 and 1931*

Name	1930		1931	
	toria (November 19-25 December 1-7)	*sarson* (January 13-19 December 7-13)	*toria* (November 11-17 December 7-13)	*sarson* (January 24-30 February 13-19)
Sepsis sp.	..	98	3	66
S. sphippium Bezzi	..	7	..	2

Sepsis sp. is a slenderly built insect. After every 'feed' it may clean its smooth body for as long as nine minutes before visiting another flower. It is a sluggish and an erratic worker but because of its abundance its value as a pollinating agent cannot be doubted.

Fam. CONOPIDÆ.—*Conops erythrocephala* Fab. is the only representative of this family caught in November from *toria* flowers. Its larvæ are endoparasites of *Andrena* and *Vespa*. It is, therefore, an unwelcome visitor to *toria* flowers.

Fam. ORTALIDÆ.—*Chrysomyza demandata* Fab. is the only representative of this family secured from *toria* and *sarson* flowers. Because of its very small numbers, it is useless as a pollinating agent.

Fam. CORDYLURIDÆ.—Only two specimens of *Scatophaga* sp. were secured from *sarson* in 1930. It is useless as a pollinating agent.

Fam. TRYPETIDÆ.—*Dacus zonatus* Saund. is the representative of this family that was secured only once from *toria* flowers. It is useless as a pollinating agent.

Fam. EMPIDÆ.—*Hilara* sp. is the only representative of this family of predaceous flies collected from *sarson* which, becuase of its very rare occurrence, is useless as a pollinating agent.

Fam. MILICHIIDÆ.—*Desmometopa M-nigrum* Zett. is the only representative of this family which was collected only once. It is useless for pollination.

Order LEPIDOPTERA

Names and numbers of the Butterflies collected from *toria* are given below: they were never found visiting *sarson* flowers.

TABLE XVII

Showing names and numbers of Butterflies collected from toria *during 1930 and 1931*

Name	1930	1931
	toria (November 19-25 December 1-7)	*sarson* (November 11-17 December 7-13)
DANAIDÆ :		
Danaus chrysippus (Linn.)	6	11
NYMPHALIDÆ :		
1. *Precis orithya* Linn.	..	1
2. *Vanessa cardui* (Linn.)	1	2
3. *Hypolimnas misippus* Linn.	..	1
PIERIDÆ :		
1. *Catopsilia crocale* Cram.	5	7
2. *Anaphœis mesentina* Cram. =*aurota* Fab.	5	4
3. *Pieris brassicæ* Linn.	1	2
LYCÆNIDÆ :		
Polyommatus sp.	1	..
HESPERIIDÆ :		
Badamia exclamationis Fab.	1	1

The Butterflies mentioned in Table XVII above visit flowers for feeding on nectar.

To obtain nectar a Butterfly suspends itself from petals and simultaneously probes the nectaries with its extended proboscis. To reach the next flowers it may either 'flutter' across the entire bunch of flowers or may fly to it. On an average a Butterfly may visit one flower in one minute.

Because of their hairy bodies and presence both during fine and inclement weather the value of Butterflies as pollinating agents cannot be doubted.

Fam. PYRALIDÆ.—*Noctuelia floralis* Hubn. is the only representative of this family secured from *toria* and *sarson* flowers. It is nocturnal and whether it visits these flowers in sufficiently large numbers at night to play any part in their pollination yet remains to be ascertained.

Fam. ARCTIIDÆ.—*Utetheisa pulchella* Linn. was about as common as *D. chrysippus* Linn. During feeding it crawls over the flowers rather sluggishly ; as such its value as a pollinating agent cannot be doubted.

Fam. NOCTUIDÆ.—*Earias insulana* (Bosid.) and *Laphygma exigua* Hub. are the only representatives of this family secured from *toria* and *sarson* flowers respectively. They were evidently accidental visitors.

A single caterpillar of *Plusia chalcytes* Fab. was found damaging *toria* flowers in December, 1930.

Fam. LYMANTRIIDÆ.—*Euproctis* sp. was secured from *toria* flowers only once.

Order COLEOPTERA

Fam. CARABIDÆ.—One specimen of *Pterostichus leus* Andr.—a representative of this family of nocturnal and predaceous beetles—was secured in November.

Fam. NITIDULIDÆ.—*Hoptoncus lutelus* Chevr. is the only member of this family of which two specimens were collected from *toria* and *sarson* flowers.

Fam. COCCINELLIDÆ.—Four species namely, *Chilomenes sexmaculata* Fab., *Coccinella septempunctata* (Linn.), *C. undecimpunctata* Linn. and *Adonia variegata* subsp. *doubledayi* Muls. of this family were secured from *toria* and *sarson* flowers. They usually abound in *toria*.

Larvae and adults of these predaceous beetles move about actively among *toria* and *sarson* flowers in search of their prey, e.g., Aphididae. The larvae are exclusively carnivorous, but the adults alternate their insect food with nectar. Therefore the greatest good they do is to destroy the injurious Mustard Aphis (*Siphocoryne indobrassicae* Das). Also, because of their body structure and assiduity with which they search out their prey, their value in the transfer of certain amount of pollen cannot be doubted.

Fam. DERMESTIDÆ.—*Attagenus bifasciatus* Oe. is the only representative of this family which has been secured from *toria* flowers.

It feeds on nectar and as many as five of them may be found in the same flower. During feeding its body lies parallel to the style with its head directed towards the nectaries. It may remain in this position for as long as 12 minutes.

It visits *toria* flowers in January when the crop is ready to be harvested. This fact coupled with its sedentary habits marks it out to be useless as a pollinating agent.

Fam. MELYDRIDÆ (*Malachiidæ*).—A single specimen of *Laius malleifer* Champ.—a representative of this family—was collected in November.

Fam. TENEBRIONIDÆ.—A single specimen of *Opatroides vicinis* Fairm.—a representative of this family—was collected in January.

Fam. CHRYSOMELIDÆ.—About six specimens of the dreaded *Aulacophora foveicollis* Luccap. were collected from November to February. This insect

winters over as an adult and therefore the specimens which were collected had evidently come out to 'enjoy' the sunshine.

Fam. CURCULIONIDÆ.—Two specimens of *Myllocerus maculosus* Desb. were collected in December. Like *Aulacophora* this insect also winters over as an adult.

Order NEUROPTERA

Fam. CHRYSOPIDÆ.—*Chrysopa* sp. is the only representative of this family which has been collected from the two crops. Though useless as a pollinating agent, its larva does good work in destroying the Mustard Aphis, each larva killing 25-28 Aphids per day.

Order ORTHOPTERA

Fam. MANTIDÆ.—*Creobroter gemmatus* Stoll. is the only representative of this family secured from flowers. It preys upon insect visitors to *toria* and *sarson* flowers and is, therefore, an undesirable creature.

Order ODONATA

Fam. LIBELLULIDÆ.—*Pantala flavescens* Linn.—a representative of this family—was occasionally seen settled on *toria* and *sarson* plants. Its visits were purely for the purpose of preying upon insects making up the fauna of the two crops but what pracisely they preyed upon could not be ascertained.

Order THYSANOPTERA

Fam. AEOLOTHRIPIDÆ.—(?) *Aeolopthrips* sp. is the only representative of this family collected from *toria* and *sarson* flowers. It feeds both on nectar and sap of flowers: it obtains the latter substance by lacerating the flower tissue with its rasping-sucking mouth-parts.

Order RHYNCHOTA

Fam. PENTATOMIDÆ.—The Painted Bug, *Bagrada picta* (Fab.), is a serious pest of *Brassicae*. It is fairly common in *toria* in November where it is seen settled on flower-buds sucking sap with its stylets. Seriously attacked flower-buds open badly and imperfectly.

Dolycoris indicus Stal. and *Nezara viridula* (Linn.) were less abundant and of absolutely no value as pollinating agents.

Fam. COREIDÆ.—One specimen of *Liorhyssus hyalinus* Fab. collected in February from *sarson* was evidently an accidental visitor and as such useless as a pollinating agent.

Fam. LYGAEIDÆ.—One specimen each of *Spilostethus pandurus* (Scop.), *Graptostethus servus* (Fab.) and *Oxycarenus laetus* Kirby was collected in December, January and February respectively. Because of their small numbers Lygaeids are of no importance in pollination.

Fam. PYRRHOCORIDÆ.—The Red Cotton Bug, *Dysdercus cingulatus* (Fab.), is very rarely met with in *toria* and *sarson* and is, therefore, useless as a pollinating agent.

Fam. MEMBRACIDÆ.—The common Tree Hopper, (?) *Leptocentrus* sp which abounds on 'Sirin' (*Albizzia lebbek*) was collected only once in November.

Fam. FULGORIDÆ.—The sugarcane Leaf Hopper, *Pyrilla perpusilla* (Walk.), is a pest of sugarcane and wheat: the two specimens collected in November were evidently accidental visitors.

Fam. APHIDIDÆ.—The common Mustard Aphis, *Siphocoryne indobrassicae* Das. (=*pseudobrassicae* Davis) abounds on *toria* and *sarson*. It congregates in enormous numbers on the stalk of the inflorescence, flower-buds and flowers from which it sucks vital fluids with its stylets. The attacked stalk gnarls badly and the flowers open poorly, while the pods formed from such flowers are misshapen and usually do not develop any seed. It is, therefore, a serious pest whose absence rather than presence is to be desired.

RELATIVE SIGNIFICANCE OF THE IMPORTANT POLLINATORS

A method of study.—It will be observed from the foregoing pages that the insect visitors of *toria* and *sarson* flowers constitute a complex phenomenon of organic activity. Some are sap-feeders, e.g., *Bagrada picta* (Fab.) *Siphocoryne indobrassicae* Das. (=*pseudobrassicae* Davis.), etc., some are predaceous upon other insects, e.g., *Creobroter gemmetus* Stoll., *Liris haemorrhoidalis* (Fab.), *Philanthus depredator* Smith, etc., a few are parasites of other insects, e.g. *Nomada* sp., a few are accidental visitors to these crops, e.g. *Dysdercus cingulatus* (Fab.), *Pyrilla perpusilla* Walk., etc., whilst a vast majority (particularly Hymenoptera and Diptera) visit these flowers for pollen and nectar.

To study the relative significance of the insect visitors to *toria* and *sarson* flowers as pollinating agents the following method was adopted :—

Two healthy shoots of the same age were selected on an easily accessible plant and their opened and about to open flowers were nipped off with scissors. One of these shoots was used for cross-pollination by insects and the other as control. The flower-buds were carefully examined for Thrips and other small insects. Each branch was then enclosed in a muslin bag (30 in. by 15 in.) big enough to provide ample space for its growth. The top of the bag was fastened to an inverted L shaped bamboo stick hammered in the ground. The bags thus secured are able to stand a casual storm which may occur during the growing season of *toria* or *sarson*. Six insects were introduced daily between 12 noon to 2 P.M. into each bag. These insects were captured in glass tubes and immediately put into the bags from the upper end. At the close of each experiment all the unopened flowers enclosed in a bag were nipped off and the bag tied up in the usual manner so as to allow the seeds to mature. In due course the plants were harvested and the seeds formed in each pod were counted. The results are presented in Table XVIII. (Only a typical example is given in each case).

It will be observed from Table XVIII that the largest number of normal seeds per pod was found in bags with *Andrena ilerda* Cam. and *Apis florea* Fab., while the lowest number of seeds was formed in bags with *Sepsis* sp. and *Trichometallea pollinosa* Tns.

It will also be observed from Table XVIII that the average number of normal seeds formed per pod in the case of the experimental plants was

TABLE XVIII

Showing relative significance of the insect pollinators a : *bag with insects.* b : *Control.* c : *free flowering*

	Andrena ilerda Cam.			*Apis florea* F.			*Halictus* sp.			*Philanthus depredator* Smith			*Eristalis* sp.			*Sepsis* sp.			*T. pollinosa* Tns.		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Total flowers .	118	111	73	215	303	50	68	66	53	108	170	85	176	124	30	26	21	14	220	166	55
Pods formed .	115	22	73	202	45	50	58	34	51	40	16	78	139	51	28	5	4	13	102	53	54
Per cent pod setting	97·46	19·82	100·0	93·98	14·85	100·0	85·99	51·51	96·26	37·0	9·4	91·8	78·98	41·13	93·33	19·2	19·0	92·8	46·4	31·9	98·2
Average No. of normal seed per pod.	7·53	1·42	18·51	6·95	1·54	18·62	3·68	1·88	20·02	1·1	0·8	12·2	4·38	2·07	28·32	1·2	0·8	10·7	1·6	1·7	17·2

TABLE XIX

Showing the total number of insects collected during November-March, 1930 and 1931.

	1930				1931			
	toria		*sarson*		*toria*		*sarson*	
	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent
HYMENOPTERA—								
Andrena ilerda	586	43·73	76	5·35	1420	39·78	40	3·46
Apis florea	221	16·49	690	48·62	684	19·16	602	52·07
Philanthus depredator	90	6·71	..	..	118	3·30	..	..
Halictus sp.	52	3·88	89	6·27	367	10·28	46	3·98
Nomada spp.	65	4·85	38	2·67	163	4·56	23	1·98
Other Hymenoptera	98	7·31	60	4·22	183	5·12	126	10·89
DIPTERA—								
Eristalis spp.	50	3·73	90	6·34	48	1·34	87	7·52
Trichometallea pollinosa	64	4·77	74	5·21	62	1·73	58	5·01
Sepsis sp.	..	..	211	14·86	16	·44	69	5·96
Musca sp.	..	..	5	·35	35	·98	2	·17
Rhinia discolor	4	·29	3	·21	135	3·78	6	·51
Other Diptera	49	3·65	58	4·08	146	4·09	75	6·48
LEPIDOPTERA	10	·74	16	1·12	66	1·84	8	·68
COLEOPTERA	23	1·71	4	·28	60	1·68	9	·77
RHYNCHOTA	31	2·31	..	..	48	1·34	4	·34
NEUROPTERA	1	·07	..	..	15	·42	1	·08
THYSANOPTERA	..	..	8	·56	..	..	..	..
ORTHOPTERA	..	..	..	..	3	·08	..	
Total	1344	..	1422	..	3569	..	1156	..
GRAND TOTAL	7491	..	..	..	..	..	..	..

TABLE

Showing names and numbers

Toria flowers (14-12-1931)	8-40—9 hrs.	9—10 hrs.	10—11 hrs.	11—12 hrs.
Inflorescence with 18 flowers	*Trichometallea pollinosa* . 1	*Rhinia discolor* . 1	*Andrena ilerda* . 2	*Andrena ilerda* . 5 *Apis florea* . 2 *Musca* sp. . 1 *Anthophora vedetta* . . 1
A marked flower of the above inflorescence	*Trichometallea pollinosa* . 1	...	*Andrena ilerda* 2 *Anthophora vedetta* . 2	...
Single flower, others clipped off.	...	...	*Andrena ilerda* . 8	*Andrena ilerda* . 5 *Musca domestica nebulo* . . 1 *Eristalis* sp. . 1 *Trichometallea pollinosa* . 1
Sarson flowers (19-2-1931)				
Inflorescence with 20 flowers	*Eristalis* sp. . 2 *Sepsis* sp. . . 1	*Musca* sp. . 5 *Sepsis* sp. . . 3 *Halictus* sp. . 1	*Musca* sp. . 5 *Sepsis* sp. . . 1	*Apis florea* . 8 *Sepsis* sp. . 4 *Andrena ilerda* . 1
A marked flower of the above inflorescence.	...	*Sepsis* sp. . . 3	*Halictus* sp. . 1	*Apis florea* . 2
Single flower, others clipped off.	*Musca* sp. . 2 *Rhinia discolor* . 1	*Eristalis* sp. . 1	...	*Apis florea* . 2 *Sepsis* sp. . . 1

XX

of insects visiting between

12—13 hrs.	13—14 hrs.	14—15 hrs.	15—16 hrs.	16—17 hrs.
Andrena ilerda . 13	*Andrena ilerda* . 28	*Andrena ilerda* . 25	*Andrena ilerda* . 8	*Sphaerophoria indiana* . . 1
Apis florea . . 3	*Halictus* sp. . 1	*Chrysomyza demandataza* . 1	*Apis florea* . 2	*Anthophora vedetta* . . 1
Eristalis sp. . 2	*Apis florea* . 1	*Musca* sp. . 1	*Musca* sp. . 2	
Musca sp. . . 1	*Musca domestica nebulo* . . 1		*Eristalis* sp. . 2	
	Rhynchota . 1		*Philanthus depredator* . . 1	
....	*Andrena ilerda* . 4	*Andrena ilerda* . 6	*Philanthus depredator* . . 1	...
	Apis florea . 1			
Andrena ilerda . 3	*Andrena ilerda* . 10	*Andrena ilerda* . 4	*Andrena ilerda* . 4	*Rhinia discolor* . 1
	Apis florea . 3	*Apis florea* . 2	*Apis florea* . 1	
			Eristalis sp. . 1	
Apis florea . . 17	*Apis florea* . 21	*Apis florea* . 21	*A. florea* . . 9	*A. florea* . . 2
Sepsis sp. . 7	*Halictus* sp. . 4	*Sepsis* sp. . . 3	*Sepsis* sp. . . 6	*Sepsis* sp. . . 2
			Musca sp. . . 2	
Musca sp. . . 2	*Trichometallea polliniosa* . 2	*A. ilerda* . . 2	*A. ilerda* . . 1	
Andrena ilerda . 2	*Sepsis* sp. . . 2	*Halictus* sp. . 1	*Helictus* sp. . 1	
Halictus sp. . 2	*Andrena ilerda* . 1	*Musca* sp. . 1		
	Eristalis sp. . 1	*Eristalis* sp. . 1		
Apis florea . . 1	*Apis florea* . 3	*A. florea* . . 3	...	*A. florea* . . 2
Andrena ilerda . 1	*Andrena ilerda* . 1	*Halictus* sp. . 1		
A. florea . . 4	*A. florea* . . 5	*A. florea* . . 3	*A. florea* . . 3	*Musca* sp. . 1
A. ilerda . . 1	*A. ilerda* . . 2		*A. ilerda* . . 1	
Sepsis sp. . . 1	*Sepsis* sp. . . 2			

considerably below that of the free-flowering plants. This was to be expected. When introduced (or rather 'imprisoned') in a bag an insect flew about excitedly so as to discover an exit for escape. By the time it settled down very little pollen was left on its body to ensure complete pollination.

Table XVIII (Control bags) also shows that *toria* and *sarson* plants are not entirely self-sterile for a certain amount of self pollination does take place in these two plants. This corroborates the observations of Ali Mohd. *et al.* [1931].

Table XIX gives the total number of insects collected during November-March, 1930 and 1931, as well as the names of those insects which predominated amongst the insect visitors, the rest being lumped together under their respective orders. Numbers and percentages, however, are given in all cases.

A study of Table XIX justifies the following conclusions :—

1. *Andrena ilerda* Cam. constitutes 40-44 per cent of the insect visitors to *toria* flowers. In *sarson* it makes up 3-5 per cent only of the insect visitors.
2. *Apis florea* Fab. constitutes 49-52 per cent of the visitors to *sarson*, but only 16-17 per cent to *toria* flowers.
3. The population of *Halictus* sp. in the two crops varies from 4-10 per cent.
4. *Eristalis* spp. and *Trichometallea pollinosa* Tns. are the only representatives of Diptera that visit *toria* and *sarson* flowers uniformly and regularly. Between themselves they constitute 3-13 per cent of the insect visitors to these flowers.
5. Although the body of *Sepsis* sp. is smooth, but because of its abundance its value as a pollinating agent cannot be doubted.
6. Other insects because of their small numbers, cannot be considered as important pollinators. That they do effect a certain amount of pollination, cannot, however, be doubted.

Hourly frequency of the insect visitors

Observations were made on the hourly frequency of insect visitors to *toria* and *sarson* flowers from 8th December 1931 to 14th December 1931 and from 11th February 1931 to 19th February 1931 daily for 8 hours and 20 minutes. The results of two such observations (one for *toria* and one for *sarson* are given in Table XX. The method adopted was the same as described by Ali Mohd. *et al.* [1931].

It is seen from Table XX that :—

1. Before 10 a.m. *toria* and *sarson* flowers are mostly visited by Dipterous insects, while after 4 P.M. both Dipterous and Hymenopterous insects are present in almost equal numbers.
2. *Halictus* sp. begins its visits after 9 A.M., *Andrena ilerda* Cam. after 10 A.M., and *Apis florea* Fab. after 11 A.M. From 11 A.M. upto 4 P.M. these three insects completely outnumber all other insect visitors. (These generalizations are confirmed by the remaining 14 observations as well).

SUMMARY

The insect visitors to *toria* and *sarson* flowers were collected for 131 days during November to February in 1930 and 1931, at Lyallpur. This collection includes 105 different species representing 55 families of 9 Orders of the Class Insecta. The habits and usefulness of these insects are discussed and it has been found that *Apis florea* Fab., *Andrena ilerda* Cam., *Halictus* sp. and *Eristalis tenax* Linn. are the most important pollinators.

A study of the hourly frequency of the insect visitors also confirms this conclusion.

Philanthus depredator Smith.—An insect predaceous upon bees—(in its relation to Indian bees) is brought to light for the first time. Its habits and capacity for destruction of bees are described.

ACKNOWLEDGEMENTS

I am greatly indebted to Khan Bahadur M. Afzal Husain for his suggesting the problem and for his guidance during the progress of the work. I am also much indebted to Ch. Ali Mohd. for his providing facilities for the work and to Ch. Mohd. Afzal for supplying me with the metereological data given in Table I. I wish to thank my colleagues, particularly Mr K. G. Bhandari, who helped mein this investigation by collecting insects. Thanks are also due to the authorities of the British Museum, London, for determining 70 per cent of the insects listed, the remaining 30 per cent having been determined by myself.

REFERENCES

Afzal Husain, M. (1930). *Rept. Dept. Agric. Punjab*, Pt. II, **1**, 159
Alderman, W. H. (1918). *Proc. Amer. Soc. Hort. Sci.*, **14**, 94-101
Ali Mohd., R. D. Singh and Z. Alam (1931). *Ind. J. Agric. Sci.* **1**, 109-36
Ali Mohd. (1935). *Ibid*, **5**, 1-30
Auchter, E. C. (1922). *Proc. Amer. Soc. Hort. Sci.*, **18**, 51-80
Burkill, I. H. (1906) *J. and Proc. Asiatic Soc., Bengal*, **2**, 511-25
Burkill, I. H. (1907). *Ibid.* **3**, 517-26
Burkill, I. H. (1908). *Ibid.* **4**, 179-231
Burkill, I. H. (1909). *Ind. Ins. Life* **1**, 222-3
Burkill, I. H. (1911). *J. and Proc. Asiatic Soc., Bengal*, **6**, 101-7
Farrar, C. L. (1931). *J. Eco. Ento.* **24**, 622-7
Ghosh, C. C. (1915). *Imp. Inst. Agric. Res. Pusa Bull.* **46** (second edition)
Imms, A. D. (1934). *A general text book of Entomology, London*
Treherne, R. C. (1923). *15th Ann. Rept. Quebec Soc. Prot. Plant*, 47-59
Waite, M. B. (1895). *Div. Veg. Path. U. S. Dept. Agric. Bull.*
Waite, M. B. (1899). *U. S. Dept. Agric. Year Book*, 167-80
Williams, R. D. (1925). *Welsh Plant Breeding Sta. Bull.* **4**, Ser. H.

THE HOT FERMENTATION PROCESS FOR COMPOSING TOWN REFUSE AND OTHER WASTE MATERIAL*

III. THE HOT FERMENTATION VS. AEROBIC SYSTEMS OF COMPOSTING

BY

C. N. ACHARYA, M.Sc., PH.D., F.I.C.

Department of Biochemistry, Indian Institute of Science, Bangalore

(Received for publication on 6 October 1939)

(With Plate VI)

IT was observed in Part I of this series [Acharya and Subrahmanyan, 1939] that previous studies carried out at Bangalore and at other centres showed that considerable losses of nitrogen and of organic matter occur in the aerobic methods of composting, as ordinarily practised in this country, and that such losses are particularly great while composting street-sweepings with nightsoil. Preliminary trials reported in Part I gave hopes of minimizing the above losses to a considerable extent by adopting the hot fermentation process, wherein the air supply is cut off after five or six days and the mass is allowed to ferment anaerobically for about three months. The various factors which go to control the efficacy of the hot fermentation process have been studied in detail and the results obtained have been reported in Part II [Acharya, 1939]. Having standardized the conditions of the process, it appeared advisable to verify the soundness of the preliminary indications reported in Part I, by carrying out comparative tests of the aerobic and hot fermentation process under controlled conditions on a uniform type of material and on the large scale.

Ragi straw was chosen for the initial trials, with a view to secure uniformity of material and minimize errors in sampling, but in the later experiments street sweepings, screened into the 'organic' and 'soil' fractions were used. Different starters such as ammonium sulphate, cattle dung and urine and nightsoil were tried. The experiments were first carried out in the laboratory in glazed jars, then outdoors in cement-coated concrete cisterns (2 ft. cubes) and finally on the large scale in trenches and overground heaps.

The raw materials used in the experiments had the average chemical composition shown in Table I.

*Parts I and II of this series appeared in *Ind. J. Agric. Sci.* **9**, 741—4 and 817—33

TABLE I

Analysis of raw materials used

Constituents	*Ragi* straw per 100 gm. (sundried)	Cattle dung per 100 gm. (fresh)	Cattle urine per 100 c.c. (diluted)	Nightsoil per 100 gm. (fresh)	Street sweeping screened into	
					Leaves fraction per 100 gm. (air-dry)	Soil fraction per 100 gm. (air-dry)
	gm.	gm.	gm.	gm.	gm.	gm.
1. Dry matter . . .	94·98	20·02	0·809	19·50	90·40	97·50
2. Ash free organic matter .	86·27	15·11	0·359	15·30	54·30	6·20
3. Carbon	38·22	6·60	0·247	9·30	30·71	3·07
4. Nitrogen . . .	0·50	0·278	0·102	1·10	1·23	0·24
5. Ash and non-volatiles .	8·71	4·91	0·450	4·20	36·10	91·30
6. Moisture	5·02	79·98	99·191	80·50	9·60	2·50

JAR EXPERIMENTS

Ragi straw, cut into small bits $\frac{1}{2}$ in. to 1 in. long, was taken up for decomposition, using nightsoil as the starter. Varying quantities of nightsoil necessary to secure different initial C : N ratios of the composts, as shown in Table II, were weighed into porcelain dishes, the quantities of water shown in the above table were added, the whole well mixed and added in portions to the jars containing *ragi* straw so as to promote uniform admixture. The initial C : N ratios thus obtained were 40 : 1, 30 : 1, 20 : 1 and 15 : 1.

TABLE II

Jar experiments

C : N Ratio (approximate)	*Ragi* straw taken	Nightsoil added (fresh weight)	Water added
	gm.	gm.	c.c.
40 : 1	200	80	235
30 : 1	200	150	220
20 : 1	200	300	190
15 : 1	200	600	130

One series was allowed to ferment aerobically in shallow wide jars and the samples were turned over once in 10 days and moistened with water, so as to keep the mass moist to the touch, but not to such an extent as to allow any water to accumulate at the bottom of the jar. A parallel series was allowed to ferment by the hot fermentation system. The jars were left undisturbed for six days, at the end of which period the samples were pressed down and covered over with a layer of mud paste and over it a layer of earth. At the end of three months, both series were taken out and the contents dried at 50°—60°C. weighed, powdered and analysed for dry matter, carbon, nitrogen and ash according to the methods followed in Part II of this series.

The percentage composition of the samples obtained in the two series at the end of composting and their C : N ratios, are shown in Table III. It is sometimes the practice to judge the over-all efficiency of a composting process by reference to the analytical composition of the final compost obtained. While this criterion may be the deciding factor in comparing processes, one of which produces a compost of low manurial value (say with a nitrogen content less than 0·5 per cent on dry matter) and another which produces a compost of high manurial value (say, with a nitrogen content of two per cent or over, on dry matter), it cannot be considered to have the same value in cases where both the processes under comparison yield composts above the average quality (i.e. over one per cent nitrogen on dry matter). In such cases, the efficiency of a composting process can best be judged, by taking into consideration the total quantity of manure obtained and the total recovery of manurial constituents such as nitrogen and organic matter secured in the different processes.

The possibility of arriving at misleading inferences by relying solely on the former system of judging the efficiency of a composting procedure will be evident from a reference to Table III. The analytical data presented therein would lead one to infer that the aerobic method of composting is more efficient than the hot fermentation process, since it yields a manure of better quality, containing a higher percentage of nitrogen. In three out of four comparisons (i.e. except at initial C : M ratio of 15 : 1) the nitrogen content of the aerobically prepared manure is definitely higher than that of hot fermented compost. The C : N ratio of the composted material is also narrower in the former case. But as pointed out in the last paragraph, these indications must be judged in conjunction with the total quantities of manure obtained in the two cases and the corresponding recoveries of nitrogen and of organic matter obtained. The importance of this latter consideration will be evident to the farmer who aims at getting the maximum yield of good quality manure from the raw materials he is starting with.

It will be noted from Table III that the quality of the manure obtained by the hot fermentation process is quite satisfactory, since the nitrogen content of the compost is 1·96 per cent on dry matter, even when the initial C : N ratio of the raw material was 40 : 1. The C : N ratio of the final compost varies from 20 : 1 to 10 : 1 depending on the quantity of nightsoil added.

The deciding advantage in favour of the hot fermentation process lies in the much larger amount of manure obtained by that method and the much

higher recoveries of nitrogen and organic matter secured, as compared with the aerobic methods. The relative data bearing on this point are presented in Table IV. In the aerobic methods, the yield of manure (dry weight) obtained is of the order of 30 to 38 per cent, while in the hot fermentation process it ranges from 45 to 52 per cent, i.e. nearly $1\frac{1}{2}$ times as much. A similar relationship reflects itself in the recoveries of organic carbon.

TABLE III

Jar experiments with ragi *straw—analysis of composts*

Initial C : N ratio of compost lot	Analysis on dry matter			Final C : N ratio of compost
	Ash free organic matter	Carbon	Nitrogen	
Aerobic method	per cent	per cent	per cent	
C : N ratio 40 : 1 . .	74·99	36·67	2·83	12·96 : 1
Do. 30 : 1 . . .	74·09	39·45	3·03	13·03 : 1
Do. 20 : 1 . . .	68·89	35·40	3·26	10·85 : 1
Do. 15 : 1 . . .	67·39	34·73	3·28	10·60 : 1
Hot fermentation method				
C : N ratio 40 : 1 . . .	82·77	39·45	1·96	20·16 : 1
Do. 30 : 1 . . .	80·97	39·31	2·40	16·35 : 1
Do. 20 : 1 . . .	79·25	36·02	2·87	12·54 : 1
Do. 15 : 1 . . .	75·63	33·62	3·40	9·90 : 1

The economy of nitrogen conservation in the two cases is of particular interest, since nitrogen is the most important manurial constituent present in composts. Where the initial C : N ratio of the compost material is 40 : 1, there is little to choose between the two systems of composting in regard to nitrogen conservation. Both are equally efficient in conserving over 96 per cent of the nitrogen originally present in the raw materials. When the C : N ratio is brought down to 30 : 1 or narrower, the hot fermentation process is found to conserve the original nitrogen better than the aerobic methods. The difference in efficiency between the two methods becomes more marked as the C : N ratio gets narrower.

In interpreting the data contained in Tables III and IV, it must be borne in mind that the raw material used in the present experiments is *ragi* straw, which contains a high percentage of readily decomposable constituents

TABLE IV

Jar Experiments with Ragi *straw—Recoveries of Nitrogen and of organic matter during composting*

Initial C : N ratio of compost lot	Total dry matter			Ash-free organic matter			Carbon			Nitrogen		
	Taken	Recovered	Recovery	Taken	Recovered	Recovery	Taken	Recovered	Recovery	Taken	Recovered	Recovery
	gm.	gm.	per cent	gm.	gm.	per cent	gm.	gm.	per cent	gm.	gm.	per cent
Aerobic method												
C : N ratio 40 : 1 .	216·2	66·8	30·89	199·6	50·1	25·10	77·4	24·5	31·62	1·96	1·89	96·42
Do. 30 : 1 .	232·1	75·3	32·44	211·0	55·8	26·44	84·0	29·7	35·36	2·80	2·28	81·41
Do. 20 : 1 .	266·4	93·5	35·10	237·4	64·4	27·12	97·9	33·1	33·78	4·57	3·05	66·74
Do. 15 : 1 .	335·5	126·4	37·69	289·1	85·2	29·46	125·9	43·9	34·85	8·14	4·14	50·87
Hot fermentation method												
C : N ratio 40 : 1 .	216·2	98·1	45·37	199·6	81·2	40·68	77·4	38·70	50·00	1·96	1·92	97·95
Do. 30 : 1 .	232·1	110·7	47·67	211·0	89·6	42·46	84·0	43·5	51·78	2·80	2·66	94·99
Do. 20 : 1 .	266·4	131·6	49·39	237·4	104·3	43·97	97·9	47·4	48·42	4·57	3·78	82·71
Do. 15 : 1 .	335·5	175·5	52·31	289·1	132·7	45·91	125·9	59·0	46·87	8·14	5·96	73·21

such as hemicelluloses and cellulose. The choice of such a carbonaceous material offers the optimum conditions for maximum conservation of nitrogen in the system under aerobic conditions of composting, since microbial decomposition of the carbonaceous groups is accompanied by a simultaneous stabilization or fixation of the labile nitrogen in the form of microbial bodies. If less readily decomposable materials than straw be used, as is often the case in farming practice, the conservation of nitrogen in the aerobic system may be expected to be less than the figures given in Table IV and the differences between the ' hot fermentation ' and ' aerobic ' results may be expected to be greater.

It is noteworthy that in the hot fermentation process as much as 82·71 per cent of the nitrogen is conserved even when the initial C : N ratio of the compost lot is as narrow as 20 : 1. This is of particular significance while dealing with the composting of town wastes such as street sweepings and nightsoil. As is evident from the figures given in Table I, the C : N ratio of street sweepings ranges from 20 : 1 to 25 : 1. Street sweepings in India possess generally a narrower C : N ratio than in western countries, on account of the prevailing practice of using leaves as dinner plates in many parts of this country and on account of the considerable amounts of dung and even human excreta which find their way into the sweepings. As such, a mixture of street sweepings and night-soil, under the conditions prevailing in most of our municipalities, has a C : N ratio between 20 : 1 and 15 : 1. The position is aggravated in places where the quantity of sweepings available for composting purposes (especially the organic matter fraction of sweepings) barely exceeds the weight of nightsoil collected, by the municipality. In such cases, very heavy losses of nitrogen may be expected to occur under aerobic methods of composting. The losses could be minimized considerably by adoption of the hot fermentation process.

Semi-large scale experiments with *ragi* straw

The jar experiments were followed by experiments on the semi-large scale, using 1000 lb. lots of *ragi* straw and comparing different starters such as minerals, cattle dung and urine and night-soil. The *ragi* straw was cut into bits 6 in. to 8 in. long before use. The mineral starter tried was a mixture of 40 lb. commercial grade ammonium sulphate (92 per cent purity), 50 lb. calcium carbonate (ground chalk) and 5 lb. superphosphate, for every 1000 lb. of straw. The constituents were well mixed and 1/20 portions were sprayed over every 50 lb. of straw added to the compost heap, along with five to six gallons of water to wet the material completely. The quantity of ammonium sulphate added corresponded to about 0·78 per cent nitrogen on the straw, and is approximately near the figure of 0·75 per cent N found to be optimum by Hutchinson and Richards [1921] for the rapid rotting of straw. Calcium carbonate was added to neutralize the acidity produced from ammonium sulphate and super phosphate as well as from the straw. The retentive capacity of straw for water is low, as has been observed by several workers previously, and hence it was found advisable to split up the quantity of water added, by adding 5 gallons per 50 lb. of straw at the beginning and 20 gallons of water to the 1000 lb. lot two or three days afterwards.

In the case of the straw-nightsoil composts, 75 lb. lots of nightsoil (fresh weight) were mixed with five to six gallons of water and added to 100 lb. of straw in portions at a time so that the whole was uniformly mixed. The operations were continued till all the 1000 lb. of straw had been added. It was not necessary to add further water in this case, except in the aerobic methods of composting. The amount of nightsoil added corresponded to 0·825 per cent nitrogen on the straw, which is slightly higher than the 'nitrogen factor' of straw (0·75 per cent N), as found by Hutchinson and Richards [1921] but then the nitrogen in nightsoil is in organic combination and may not be so readily or completely available for microbial utilization as the inorganic salts.

In the third series of experiments, difficulty was experienced in adding cattle dung and urine enough to supply 0·75 per cent of nitrogen on the straw, since dung contained only about 0·27 to 0·28 per cent nitrogen on the fresh weight and the cattle urine available locally was found to be diluted with water and contained only about 0·1 lb. of nitrogen for every ten gallons of urine (Table I). Usually about 20 to 25 lb. of dung are added for every 100 lb. of waste material taken for composting, and the amount of water (or urine) that can be retained by 100 lb. of dry waste material will be roughly about 10 gallons. These amounts of dung and urine will supply only about 0·17 per cent of nitrogen on the straw. In order to increase the quantity of nitrogen added, 100 lb. of dung and ten gallons of urine were added for every 100 lb. of straw. The dung was mixed with the urine in a drum and the straw was added in portions into the drum, stirred well in order to ensure complete wetting with the dung-urine solution and then added to the compost heap. The operations were continued till all the 1000 lb. of straw had been similarly treated. The amount of nitrogen so added by the dung and urine was about 0·38 per cent on the straw,—only half the required amount. It was not found possible to increase this amount further except by adding urine again at later stages, which was not feasible since the hot fermentation heaps were closed anaerobically after six days. Since the mass was sufficiently moist and retained its moisture well, in contradistinction to the case where minerals were added, further additions of urine were not possible even during the above period of six days.

The following gives an outline of the different treatments that were taken up for comparison :—

A. Ragi *straw* plus *minerals* (*ammonium sulphate, calcium carbonate and superphosphate*)

I. Hot Fermentation in bricklined and cemented trenches 4 ft. deep, 3½ feet broad and 10 ft. long.

II. Hot fermentation in earthen trenches, unbricklined, of the above dimensions.

III. Aerobic method in shallow wide trenches, 2 ft. deep and 14 ft. square.

IV. Aerobic method in overground heaps.

B. Ragi *straw* plus *nightsoil*—

V. Hot fermentation in earthen trenches, unbricklined.

VI. Aerobic method in overground heaps.

C. Ragi *straw* plus *cattle dung and urine*—

VII. Hot Fermenttation in earthen trenches, unbricklined.

VIII. Aerobic method in overground heaps.

Each trial was carried out in duplicate. In the hot fermentation system, the mass was allowed to decompose aerobically for five to six days. Temperature measurements were made to ensure that there was a satisfactory rise of temperature during this period. In the case of nightsoil composts, the temperature rapidly rose to 65°-70°C. at the end of four days. The dung-urine composts followed up with temperatures of about 60°C. at the end of the above period. In the case of the heaps treated with minerals, the onset of the decomposition was much slower, apparently due to the slowness with which the lignified straw got saturated with the mineral solutions employed. The delay in decomposition might also have been due to the absence of a vigorous microflora in the early stages. Dung and nightsoil are well known to be powerful inocula carrying the necessary organisms for decomposing cellulose and hemicelluloses. The rise in temperature in the compost treated with minerals was, therefore, slower and irregular.

The hot fermented composts, using dung or night soil as starter, were pressed well and covered over with a layer of mud paste two to three in. thick at the end of a week. Over the mud paste cover, a layer of loose earth three to four in. deep was spread, to close any cracks forming in the paste layer below. The hot fermented compost treated with minerals was packed after ten days from the start, since the initial fermentation was slower in this case. The parallel heaps, undergoing aerobic fermentation, were given turnings once in ten days and moistened to the extent necessary to keep the mass moist to the touch. The amount of water so added averaged about 20 gallons per heap at every turning.

At the end of three months, all the compost lots were opened out, carefully discarding the earth at the top of the hot fermentation trenches, and the composts were spread out uniformly on platforms which were bricklined and plastered. It was noticed that whereas the aerobically treated composts had become dark-brown and had broken down to small bits, the hot fermented composts were much lighter in colour and still retained the original shape of the straw pieces. The lighter colour was probably due to the exclusion of air, since the mass rapidly turned dark-brown on exposure to air. The colour change is probably enzymic. As regards texture, the hot fermented composts retained the original shape of the straw since they were not disturbed by being turned over, as in the aerobic method. The material, however, was well decomposed, as shown by the chemical data presented in Table VI and it readily broke down to pieces and was well incorporated in the soil by one ploughing.

After spreading the compost lots uniformly on bricklined platforms, composite samples were taken for analysis by mixing a number of small samples taken at different spots. The residual mass was weighed and stored in closed cisterns for use in field experiments later. The composite sample taken for analysis was weighed, dried at 50-60°C. and again weighed. A portion was taken for moisture determination at 100°C. and the residue was powdered and analysed for carbon, nitrogen, ash and dry matter. From

the values so obtained, the total amounts of dry matter, carbon, nitrogen and ash recovered in the whole quantity of the compost was calculated. The analytical methods used were the same as those adopted in Part I.

The data obtained are presented in Table V. It will be noticed from the above Table that the amount of ash recovered in the case of the cement lined trenches (Treatment I) is almost the same as that originally contained in the compost material at the start, including the added minerals. But in all the other treatments, viz., II to VIII, the amounts of recovered 'ash' are considerably above those present at the start, the difference in some cases going upto 500-600 per cent. of the original value. The difference is smaller in the case of the hot fermentation trenches, where the compost mass has not been disturbed during the process of composting, it is greater in the aerobic method carried out in trenches and is greatest in the aerobic method overground. The increase in apparent 'ash' is no doubt due to admixture of the compost with the surrounding soil and the admixture is greatest in the case of overground heaps which are turned over a number of times. Part of the admixture is brought about during the operation of turning the heap, but a good portion is also brought about by the agency of worms developing in the compost heap.

The large amounts of soil that are thus admixed with the compost are likely to vitiate the inferences drawn from the analytical results, unless due correction be applied for the amount of soil so admixed and the carbon and nitrogen contents of the added soil. Thus the figures given in Table V would lead one to infer that a better recovery of dry matter, representing a larger quantity of manure, is obtained by the aerobic method of composting (Treatments III, IV, VI and VIII), then by the hot fermentation system. Since the organic matter and nitrogen contents of Indian soils are low, the figures given for the recovery of ash-free organic matter, carbon and nitrogen in Table V are vitiated to a smaller extent than those for the recovery of total dry weight of manure.

A correction could be applied for the extraneous soil admixture, by analysing the soil near the locality where the composting is carried out, for its content of ash-free organic matter, carbon, nitrogen and the 'mineral' nonvolatile fraction. By considering the excess of 'ash' recovered in Treatments II to VIII as representing the above 'mineral' fraction of the admixed soil, the corresponding corrections for total dry matter, ash-free organic matter, organic carbon and total nitrogen can be calculated. These values have to be deducted from the corresponding values given in Table V.

The data so corrected for 'admixed soil' are shown in Table VI and present a truer picture of the changes undergone by the raw materials under the different systems of composting. It will be noted therefrom that the hot fermentation system gives a much higher yield of dry matter than the aerobic methods, ranging from $1\frac{1}{2}$ times to twice as much. The recoveries of ash-free organic matter and of carbon by the aerobic method are particularly low in the case of straw (being only 20 to 28 per cent. for heaps overground), since straw is rich in easily oxidizable carbonaceous groups such as the hemicelluloses and cellulose. In such cases, the difference in the relative efficiencies of the hot fermentation and aerobic methods shows itself

in an accentuated form, so far as the recovery of ash-free organic manure is concerned. In the present instance, where nightsoil had been used as the starter, the recovery of ash-free organic matter by the hot fermentation process is over thrice that obtained by the aerobic method. Though similar differences may not be obtained while dealing with more resistant types of waste material such as farm wastes or street sweepings, it is evident that appreciably higher recoveries of organic matter could always be expected from the hot fermentation method.

The conservation of nitrogen also is more efficiently secured in the hot fermentation method than in the aerobic methods, though the relative differences are not of such high magnitude as in the case of organic matter. The conservation is best in the case (Treatment VII) where dung and urine had been used as the starter, but in this case it must be remembered that the amount of nitrogen added in the starter was only about half the 'nitrogen factor' of straw. This would go to a great way to explain the very high recovery (92·12 per cent.) of nitrogen obtained in the above treatment. For the same reason, the recovery by the aerobic method also is fairly high (74·71 per cent.) But in cases where the nitrogen added in the starter is equal to or exceeds the 'nitrogen factor' of straw, as in Treatments I to VI the losses in the aerobic methods become greater and the superiority of the hot fermentation process becomes more marked.

Table VII shows the percentage composition and the C/N ratio of the composts prepared by the different methods. While the contents of ash-free organic matter and of carbon are generally higher in the hot fermented composts, the nitrogen percentage is generally lower. This is due to the fact that, though the nitrogen conservation is better in the hot fermentation process the conservation of organic matter is higher still. This is reflected in the C/N ratios of the composts obtained by the two methods. The ratio ranges from 22 to 26 in the case of the hot fermented compost, while it is narrower, viz. from 13 to 15 in the case of aerobically prepared composts. Considering the fact that the initial C : N ratio of *ragi* straw was 76 : 1, the final ratios obtained in the hot fermentation process should be considered to be satisfactory. It is generally agreed that materials with C : N ratios of 20 1 and narrower can be safely put on land without showing any adverse effects ; on the other hand, they serve to increase the available nitrogen in the soil (Waksman, 1936). In view of the fact that changing the C : N ratio from 20 : 1 to 12 : 1 or narrower still means, under practical conditions of composting, a simultaneous loss of carbon and nitrogen (Table VI) both of which are of importance in increasing soil fertility, it would obviously be preferable to stop the composting at the C : N ratio near 20 : 1 as in the hot fermentation process, and allow the rest of the decomposition to take place in the soil itself. The practical value and economic advantage of adopting this procedure can only be verified by actual field trials. A detailed account of the field trials that have been conducted with composts prepared by the hot fermentation and aerobic methods will be presented in a later communication, but it may be stated at this stage that the above trials have fully borne out the practical utility of stopping the composting at the earlier stage represented by the hot fermentation process and thus conserving the nitrogen better.

TABLE V

Semi-large scale experiments with ragi *straw—recoveries of major constituents*

(Uncorrected for soil contamination)

Materials and method of composting	Total dry matter			Ash free organic matter			Carbon			Nitrogen			Ash and Non-volatiles	
	Taken	Re-covered	Re-covery	Taken	Re-covered	Re-covery	Taken	Re covered	Re-covery	Taken	Re-covered	Re-covery	Taken	Re-covered
	lb.	lb.	per cent	lb.	lb.	per cent	lb.	lb.	per cent	lb.	lb.	per cent	lb.	lb.
Ragi *straw+Ammonium sulphate*														
I. H. F. in bricklined Trench .	990	634	64·04	863	538·8	62·43	382	232·1	60·75	12·81	10·47	81·74	87·0	95·2
II. H. F. in earthen trench unbricklined.	990	703	71·03	863	474·3	54·96	382	206·6	54·09	12·81	9·52	74·32	87·0	228·7
III. Aerobic in shallow trench .	990	787	79·50	863	306·4	35·50	382	151·4	39·63	12·81	8·06	62·92	87·0	480·6
IV. Aerobic in overground heaps	990	816	82·43	863	215·8	25·00	382	110·8	28·99	12·81	7·29	56·92	87·0	600·2
Ragi *straw+Nightsoil*														
V. H. F. in earthen trench .	1,100	925	84·09	978	618·3	63·23	451·8	264·1	58·45	13·25	11·74	88·61	130·9	306·7
VI. Aerobic in overground heaps	1,100	976	88·72	978	199·4	20·39	451·8	98·1	21·72	13·25	7·69	58·03	118·5	776·6
Ragi *straw+Dung+Urine*														
VII. H. F. in earthen trench .	1,158	796	68·74	1,018	515·1	50·62	450·5	214·9	47·69	8·78	8·16	92·94	140·5	280·9
VIII. Aerobic in overground heaps	1,158	934	80·65	1,018	221·5	21·74	450·5	92·4	20·51	8·78	6·85	78·00	140·5	712·5

TABLE VI

Semi-large scale experiments with ragi *straw—recoveries of constituents after correction for soil contamination*

Materials and method of composting	Total dry matter			Ash free organic matter			Carbon			Nitrogen		
	Taken	Recovered	Recovery	Taken	Recovered	Recovery	Taken	Recovered	Recovery	Taken	Recovered	Recovery
	lb.	lb.	per cent	lb.	lb.	per cent	lb	lb.	per cent	lb.	lb.	per cent
Ragi *straw+Am. sulphate*												
I. H. F. in bricklined trench .	990	634	64·04	863	538·8	62·43	382	232·1	60·75	12·81	10·47	81·74
II. H. F. in earthen trench unbricklined.	990	561	56·67	863	472·8	54·78	382	205·7	53·86	12·81	9·45	73·77
III. Aerobic in shallow trench .	990	393	39·70	863	302·0	34·99	382	149·0	39·00	12·81	7·86	61·35
IV. Aerobic in heaps overground	990	303	30·61	863	210·2	24·35	382	107·6	28·17	12·81	7·04	54·96
Ragi *straw + Nightsoil*												
V. H. F. in earthen trench .	1,100	750	68·19	978	616·4	63·04	451·8	263·0	58·21	13·25	11·65	87·94
VI. Aerobic in heaps overground	1,100	318	28·91	978	192·3	19·66	451·8	94·1	20·83	13·25	7·36	55·55
Ragi *straw+Dung+Urine*												
VII. H. F. in earthen trench .	1,158	654	56·48	1,018	513·6	50·47	450·5	214·0	47·50	8·78	8·09	92·12
VIII. Aerobic in heaps overground	1,158	356	30·74	1,018	215·2	21·14	450·5	88·8	19·71	8·78	6·56	74·71

TABLE VII

Semi-large scale experiments with ragi *straw—analysis and C/N ratio of composts*

Materials and method of composting	Initial C/N ratio of compost lot	Analysis on dry material			Final C/N ratio of compost
		Ash free organic matter	Carbon	Nitrogen	
Ragi *straw+Am. sulphate*		per cent.	per cent.	per cent.	
I. H. F. in bricklined trench.	29·83 : 1	84·98	36·61	1·651	22·17 : 1
II. H. F. in earthen trench unbricklined.	29·83 : 1	84·26	36·67	1·685	21·77 : 1
II. Aerobic in shallow trench.	29·83 : 1	76·85	37·91	2·000	18·95 : 1
IV. Aerobic in heaps over-ground.	29·83 : 1	69·37	35·52	2·324	15·29 : 1
Ragi *straw+Nightsoil*					
V. H. F. in earthen trench.	34·10 : 1	82·19	35·06	1·553	22·57 : 1
VI. Aerobic in heaps over-ground.	34·10 : 1	60·47	29·59	2·315	12·78 : 1
Ragi *straw+Dung+Urine*					
VII. H. F. in earthen trench.	51·31 : 1	78·52	32·72	1·237	26·45 : 1
VIII. Aerobic in heaps over-ground.	51·31 : 1	60·45	24·95	1·843	13·54 : 1

CISTERN EXPERIMENTS WITH TOWN REFUSE

As stated in an earlier paragraph, straw is a highly carbonaceous material which shows in an accentuated form the differences between the two systems of composting under comparison, and it seemed therefore advisable to repeat the experiments using a more resistant material such as town refuse, in place of *ragi* straw. In order to secure a certain degree of uniformity in the lots taken for the different comparisons, the sweepings were sieved through an expanded metal sieve set at 5/8 in., into a fraction, which consisted mostly of soil and ash, and another fraction consisting mostly of leaves, paper and other organic materials. Under Indian conditions, where there is plenty of vegetation in towns, the second fraction consists mostly of leaves. For

convenience of nomenclature, the two fractions into which the street sweepings are sieved are designated respectively as the 'soil' and 'leaves' fractions. The average chemical composition of the two fractions is shown in (Table 1).

The experiments were carried out in the first season in cement-coated concrete cisterns 2 ft. × 2 ft. × 2 ft. in dimensions. Nightsoil and cattle dung *plus* urine were compared as starters. Since in some municipalities there is a custom of sieving out the 'organic matter' fraction of street sweepings and using that alone for composting purposes and other municipalities use a mixture of both fractions, it seemed advisable to compare both systems. It has been already reported in Part II of this series [Acharya, 1939] that the addition of moderate quantities of the soil fraction of street sweepings exerted a beneficial effect on the course of the decomposition and on nitrogen conservation and that a quantity of soil corresponding to half the weight of night soil taken for composting appeared to be optimum.

(*i*) *Cistern experiments with street sweepings and nightsoil*

In the series where nightsoil was added as the starter, 100 lb. lots of the 'leaves' fraction of street sweepings, with and without the addition of 50 lb. of the 'soil' fraction, were uniformly mixed in portions inside the cisterns, with 100 lb. of nightsoil diluted with five to six gallons of water. The following treatments were compared using duplicate samples—

(*a*) aerobic decomposition throughout, with the material turned over once in 10 days and moistened when necessary ; (*b*) hot fermentation process wherein the material was covered over with a layer of mud paste and over it earth, after a preliminary period of six days aerobic fermentation ; and (*c*) anaerobic decomposition from the start, by packing the material well and covering it with mud paste and a layer of earth from the beginning.

At the end of three months, the residual material was taken out, spread on a bricklined and plastered platform, weighed and samples taken for analysis. The sampling and analtyical procedures were the same as those described earlier in this paper in Section II for the composting of *ragi* straw on the large scale.

The analytical data obtained are summarised in Table VIII. Since the experiments were carried out in cisterns and the soil covering at the top was removed carefully, there was no appreciable admixture with extraneous soil and hence no correction for 'soil contamination' was necessary as was applied in the case of the *ragi* straw experiments on the large scale described in Section II of this paper. The data presented in Table VIII confirm the previous conclusions that the hot fermentation method gives much higher recoveries of ash-free organic matter and of nitrogen than the ærobic method. In contradistinction to the experiments on *ragi* straw (Table VII), the percentage of nitrogen in the hot fermented compost is higher in the present experiment than the percentage in ærobically prepared composts. This is due to the fact that *ragi* straw is poor in nitrogen (0·5 per cent. N) and in the experiments described in Section II above only about 0·825 per cent of nitrogen was added to the straw in the form of nightsoil. The initial C : N ratio of the straw-nightsoil mixture was nearly 34 : 1. A reference to the jar experiments described in Section I above (Table III) would show that at C : N ratios

between 30 : 1 and 40 : 1, the ærobically prepared compost shows a higher percentage of nitrogen than the hot fermented compost, even though the total recovery of nitrogen by the former method is somewhat lower than that obtained by the latter method.

In the present cistern experiments, however, the organic fraction of street sweepings have been used in place of *ragi* straw and a reference to Table I would show that these are richer in nitrogen (1·23 per cent). The initial C : N ratio of the mixture of sweepings and nightsoil was about 18 : 1, which is much narrower than the ratio of 34 : 1 obtained for straw : nightsoil mixtures. A reference to Tables III and IV would show that at such narrow C : N ratios, the loss of nitrogen in the ærobic method is very high and is greater than the loss in carbon. Hence, under such conditions, the hot fermented composts show a higher percentage of nitrogen, along with a higher yield of manure than by the ærobic system. Under the conditions existing in Indian towns and villages, where the street sweepings contain a large amount of leaves and animal excreta, it is doubtful whether it would be possible to widen the C : N ratio of the mixture of sweepings and nightsoil beyond 20 : 1 at the start. Under these conditions, the losses of nitrogen by the ærobic methods are bound to be heavy.

TABLE VIII

Cistern experiments with town refuse—nightsoil as starter

Without soil	Yield of manure		Carbon		Nitrogen		Ash free organic matter	
100 lb. leaves fraction of street sweepings. 100 lb. Nightsoil	Fresh	Sundry	On sundry material	Recovery	On sundry material	Recovery	On sundry material	Recovery
	lb.	lb.	per cent	per cent	per cent	per cent	per cent	per cent
1. Aerobic Method .	126	68	23·24	39·50	1·37	39·97	38·18	37·30
2. Hot Fermentation Process.	181	85	25·30	53·74	1·62	59·09	45·45	55·51
3. Anærobic from the start.	202	92	31·57	72·59	1·79	70·68	54·09	71·50
Added soil. 100 lb. leaves fraction of street sweepings. 50 lb. Soil fraction . 100 lb. Nightsoil.								
1. Aerobic Method .	252	137	15·1	49·80	0·76	42·44	22·0	41·47
2. Hot Fermentation Process.	334	149	19·1	68·52	1·18	71·76	30·5	62·52
3. Anærobic from the start.	371	159	20·8	79·64	1·28	82·07	33·2	72·61

It will be noticed from Table VIII that the material which was anærobically packed from the very start gave the highest recovery of nitrogen and of organic matter, and it may appear as though this method would be an improvement over both the ærobic and hot fermentation methods. But the method of anærobic packing possessed several disadvantges in practice ; e.g. the system

did not promote the development of an active microflora which would decompose nightsoil, as evidenced by the fact that when the cisterns were opened out at the end of three months, the material smelt strongly of nightsoil, and undecomposed masses of nightsoil could be seen. Nitrification experiments in the laboratory, to be described in a subsequent communication, showed that a much longer initial lag period was required by the anærobically prepared composts before nitrification set in, than in the case of the hot fermented composts. This initial lag period was probably due to the presence of undecomposed carbonaceous material of the straw. Field trials with such anærobically prepared composts, to be presented in a future communication, showed that the crop response was poorer in the first season, when compared to the hot fermented composts, but was equal to them in the second season. These facts would indicate that a purely anærobic method of composting either fails to remove substances or causes the formation of substances which interfere with the nitrification processes in the soil and with plant growth. It would, therefore, seem advisable to ensure a suitable combination of the ærobic and anærobic treatments, as is done in the hot fermentation method.

It will also be noted from Table VIII that the addition of moderate amounts of the soil fraction of street sweepings improves the conservation of organic matter and to a greater extent of nitrogen. The compost appeared to be better broken down in the presence of soil. The addition of soil, however, lowers the percentage of nitrogen and of organic matter in the compost and, as already observed in Part II, it would be advisable to limit the addition of soil to the minimum quantity necessary to promote the better decay of the compost material. The proportion used in the present experiments of 2 : 1 : 2 (by weight) between the leaves fraction, the soil fraction and nightsoil would appear to work satisfactorily.

(*ii*) *Cistern experiments with street sweepings and cattle dung plus urine*

Another series of compost experiments in cisterns was run on the same lines as the previous series described in Section III (*i*) above, but with the difference that a mixture of cattle dung and urine was used as the starter instead of nightsoil. A certain amount of household (wood) ash was also added to correspond with the conditions in farming practice. For every 100 lb. of leaf material, with and without the addition of 50 lb. of soil, 25 lb. of dung and three gallons of urine were added. Extra water to the extent of eight to nine gallons was also added. The treatments compared were the same as in Section III (*i*), viz. ærobic, hot fermentation and completely anærobic, and also the influence of the addition of soil. The details of composting procedure and methods of sampling and analysis were the same as described in Section III (*i*).

The analytical results obtained are summarized in Table IX. The general trend of the results is the same as in the case of the previous experiments with nightsoil, viz., the hot fermentation method secures a better conservation of organic matter, carbon and nitrogen than the ærobic method, both as regards the percentage of these constituents present in the manure as well as in the absolute amounts recovered out of the quantities originally present in the raw materials. The anærobically prepared composts contain

a higher percentage of nitrogen, but at the same time they contain large amounts of readily oxidizable constituents of the original raw material and hence are open to the objections and drawbacks referred to in the last section III (*i*) while dealing with refuse-nightsoil composts. The protective action of the soil in lessening the loss of nitrogen and of organic matter may be noticed in this case also.

TABLE IX

Cistern experiments with town refuse—cattle urine and dung as starters

Without soil 100 lb. leaves. 10 lb. Household ash. 25 lb. dung and 3 gallons cattle urine.	Yield of manure		Carbon		Nitrogen		Ash free organic matter.	
	Fresh	Sundry	Sundry material	Recovery	Sundry material	Recovery	Sundry material	Recovery
	lb.	lb.	per cent	per cent	per cent	per cent	per cent	per cent
1. Aerobic method .	109	67	18·2	39·32	0·72	38·59	27·0	32·96
2. Hot fermentation process.	178	80	21·5	55·46	1·06	67·84	36·2	52·71
3. Anærobic from the start.	201	89	25·3	72·61	1·18	84·09	41·5	67·26
Added soil 50 lb. soil. 100 lb. leaves. 10 lb. Household ash. 25 lb. dung and 3 gallons urine.								
1. Aerobic method .	196	112	16·4	56·44	0·70	57·23	28·2	54·45
2. Hot fermentation process.	271	125	20·2	77·52	0·86	78·48	34·2	73·70
3. Anærobic from the start.	284	134	21·4	88·12	0·90	88·02	37·8	87·34

A comparison of Tables VIII and IX would show that the composts prepared by use of cattle dung and urine are appreciably poorer in nitrogen as compared with those prepared by use of nightsoil as starter. This is due to the fact that cattle dung contains only about a fourth of the nitrogen contained in nightsoil (Table I) and the quantity of cattle urine that can be added to the compost heap is limited by the capacity for absorption by the raw materials. These difficulties have been already referred to in detail in Section II above. The difference in nitrogen contents of the two starters is reflected also in the manurial values of the respective composts when they are applied to land. Nightsoil composts, if they are properly prepared, give much better crop responses, per ton of manure, than composts prepared by use of dung and urine, as has been shown by field experiments which will be reported in a further communication.

SEMI-LARGE SCALE EXPERIMENTS WITH TOWN REFUSE

The cistern experiments with town refuse were followed up by semi-large experiments, using lots of 1,000 lb. of the sieved 'leaves' fraction of street

sweepings and 500 lb. of the 'soil' fraction. In the present series of experiments an effort was made to see whether the capital cost of digging the trenches could be avoided by carrying out the hot fermentation process in overground heaps, by mud-plastering these heaps after an initial ærobic fermentation of six to seven days, and to see how such composts compare with those prepared in trenches. The following methods of composting were compared :—

(1) Hot Fermentation in underground trenches which were bricklined and plastered.
(2) Hot Fermentation in underground trenches without bricklining.
(3) Hot Fermentation method in heaps overground on bricklined platforms.
(4) Hot Fermentation method in heaps overground on platforms which were not bricklined.
(5) Aerobic process in shallow wide trenches which were not bricklined.
(6) Aerobic process in heaps overground on platforms which were not bricklined.

Two different starters were tried, viz. nightsoil and cattle dung *plus* urine. Each trial was carried out in duplicate.

In the first series using nightsoil as starter, lots of 100 lb. of 'leaves' fraction of street sweepings and 50 lb. of the 'soil' fraction were uniformly mixed within the container itself with 100 lb. of nightsoil (fresh weight) diluted with eight to nine gallons of water. The operations were repeated ten times, so that in all 1,000 lb. of 'leaves' fraction and 500 lb. of 'soil' fraction and 1,000 lb. of nightsoil were added to form a compost lot. In the parallel series using cattle dung *plus* urine as starter, 25 lb. of dung and five gallons of urine were mixed with further ten gallons of water and uniformly mixed with lots of 100 lb. of 'leaves' fraction and 50 lb. of 'soil' fraction. The operations were repeated till 1000 lb. of the 'leaves' fraction and 500 lb. of 'soil' fraction had been so treated. The moisture level was brought to about 50 per cent. at the start.

The hot fermentation composts, either in trenches or in heaps overground, were packed free from air after six days, by a layer of mud plaster and earth, as already described in section II of this paper. The 'ærobic' composts were turned over once in 15 days with watering, enough to keep the mass moist to the touch. The total amount of water so added ranged from 25 gallons per heap per turning in the initial stages to about 10 gallons towards the final stages of decomposition.

At the end of three months, the composts were taken out, spread uniformly on bricklined platforms, samples taken for analysis, the residual mass weighed, and the samples analysed according to the procedure already outlined for the semi-large scale experiments with *ragi* straw in section II above. In the present case also, it was noticed that there was a large admixture of extraneous soil in the composts prepared overground on unbricklined platforms, and to a lesser extent in trenches which were not bricklined. The contamination was still less in the case of heaps kept on bricklined platforms or in bricklined trenches. Necessary corrections have been applied for the above soil contamination, according to the method described in Section II above, and the corrected

data are presented in Tables X and XI. Table X gives the results obtained by use of nightsoil as starter and Table XI gives the corresponding data for composts prepared by use of cattle dung *plus* urine as starter.

TABLE X

Semi-large scale experiments with town refuse using nightsoil as starter.

Taken— 1,000 lb. leaf fraction of street sweepings. 500 lb. soil fraction of street sweepings. 1,000 lb. Nightsoil (fresh).	Yield of manure		Carbon		Nitrogen		Ash free organic matter	
	Fresh	Sun-dried	Analysis	Recovery	Analysis	Recovery	Analysis	Recovery
	lb.	lb.	per cent	per cent	per cent	per cent	per cent	per cent
I. Hot Fermentation in underground trenches with bricklining.	3,215	1,520	19·81	72·46	1·22	75·91	34·93	73·05
II. Hot Fermentation in underground trenches without bricklining.	3,010	1,438	18·01	62·34	1·13	66·36	31·85	63·01
III. Hot Fermentation in heaps overground on bricklined platforms.	2,760	1,325	17·84	56·90	1·19	64·34	30·39	55·39
IV. Hot Fermentation in heaps overground on platforms not bricklined.	2,620	1,280	17·05	52·53	1·10	57·58	29·55	52·02
V. Aerobic, in shallow wide trenches.	2,230	1,185	16·60	47·36	1·08	52·49	29·36	47·87
VI. Aerobic, in heaps overground.	1,980	1,042	14·98	37·58	0·99	42·09	28·89	41·41

TABLE XI

Semi-large scale experiments with town refuse using cattle urine and dung as starters

Taken— 1,000 lb. leaf fraction of street sweepings. 500 lb. soil fraction of street sweepings. 250 lb. dung. 50 gallons of urine.	Yield of manure		Carbon		Nitrogen		Ash free organic matter	
	Fresh	Sun-dry.	Analysis	Recovery	Analysis	Recovery	Analysis	Recovery
	lb.	lb.	per cent	per cent	per cent	per cent	per cent	per cent
I. Hot Fermentation in underground trenches with bricklining.	3,015	1,415	17·81	77·45	0·77	79·52	31·11	75·88
II. Hot Fermentation in underground trenches without bricklining.	2,784	1,320	17·04	69·15	0·74	71·53	28·78	65·52
III. Hot Fermentation in heaps overground on bricklined platforms.	2,645	1,275	16·47	64·54	0·69	64·12	26·27	57·76
IV. Hot Fermentation in heaps overground on platforms not bricklined.	2,496	1,190	15·13	55·32	0·63	54·75	25·66	52·64
V. Aerobic, in shallow wide trenches.	2,112	1,075	13·95	46·10	0·60	47·10	24·82	46·03
VI. Aerobic, in heaps overground	1,826	960	13·02	38·41	0·59	41·35	23·44	38·80



FIG. 1. A battery of cisterns in which the preliminary studies were carried out under controlled conditions



FIG. 2. Composting of night soil with street sweepings in trenches



It has been mentioned above that one of the objects of the present experiment was to see whether trenches could be dispensed with in the hot fermentation method and overground heaps used instead. The data presented in Tables X and XI reveal that in the case of refuse-nightsoil composts as well as refuse-dung composts, trenches gave better results than overground heaps. This was shown both in the hot fermented composts and in those ærobically prepared. The superiority of trenches to overground heaps in conserving a greater amount of nitrogen and of organic matter, has been already noticed by Aiyar [1933] and others and is attributable to the more efficient retention of moisture and the more rapid rise of temperature secured in trenches. The temperature is also maintained at a high level for a longer time in trenches. Waksman and coworkers [1939] have found that the loss of nitrogen during composting is less in cases where there is a rapid rise of temperature in the early stages ; the loss was greatest in cases where the temperature rise is slow and irregular.

That the better conservation of nitrogen and of organic matter in the hot fermentation method is not solely due to the composting being carried on in trenches in that method, is shown by comparing the results obtained (Tables X and XI) for the treatments II and IV, where both the hot fermentation and ærobic methods are carried out in trenches, and also treatments IV and VI where both the above methods have been tried on heaps overground. In both cases, the hot fermentation system has given a higher recovery of organic matter and of nitrogen, indicating that in the ærobic method, as ordinarily practised, there is a continuous loss of nitrogen, which could be avoided by packing the material anærobically after the initial stage of ærobic fermentation.

A comparison of the data shown in Table X with those given in Table XI confirm the observations made in Section III (*ii*) above, regarding the relative manurial values of composts prepared from nightsoil and cattle-dung as starters. In the present series also, the nightsoil composts show appreciably higher percentages of nitrogen and of ash-free organic matter than those prepared from dung and urine.

A comparison of treatments II and VI (Tables X and XI) would show that by adopting the hot fermentation system in trenches, it is possible to obtain recoveries of nitrogen and of organic matter which are about $1\frac{1}{2}$ times those obtained by the ærobic method overground.

Discussion

It is generally admitted that nitrogen is the most important constituent present in bulky organic manures like composts, next to the organic matter contained. Most Indian soils being deficient in phosphoric acid, the amount of this constituent also may go to a certain extent in influencing the manurial value, especially in the case of nightsoil composts which are rich in P_2O_5. But there is little likelihood of loss of phosphoric acid during the process of composting, if losses due to leaching be avoided, whereas losses of nitrogen occur often to a considerable extent and are not easily avoided.

The experiments described above have shown that the loss of nitrogen is particularly serious while dealing with the disposal of town wastes such as

nightsoil and street sweepings by the method of composting, on account of the narrow C : N ratio of the materials concerned. When dealing with materials of such narrow C : N ratio, the ærobic methods involve heavy losses of nitrogen to the extent of 50 per cent and more of the quantity originally present. The loss of nitrogen implies a proportionate decrease in the manurial value of the compost and hence in the price which the manure could obtain. Conversely, by adopting a method of composting which would minimize the loss, it would be possible to prepare a correspondingly larger quantity of manure containing the same percentage of nitrogen. By either alternative, it will be possible for a municipality or a private farmer to obtain a greater return from the available raw materials on hand. Hence arises the need for devising a method which, under practical conditions of composting, would minimize the loss of nitrogen, if not avoid it altogether. Since Indian soils are poor in organic matter, it would at the same time be an advantage if more of the organic matter could be conserved than what is done by the ærobic methods. Judged by these two tests, the hot fermentation method appears to be a distinct improvement over the ordinary ærobic methods of composting. The data given in the present paper would clearly show that in the ærobic methods of composting, especially under our Indian conditions of high temperatures and in some areas excessive rainfall, the oxidation is carried to an extreme stage, when heavy and avoidable losses of nitrogen and of organic matter occur. It would obviously be an advantage to stop the ærobic decomposition at a much earlier stage, as is done in the hot fermentation method, and allow the rest of the decomposition to proceed anærobically.

Two seeming advantages of the ærobic method of composting, which are often quoted, are : (1) the rapidity with which the composting is finished and the material is ready for application to land ; and (2) the thorough decomposition of the material to a dark-brown, friable powder which could be easily incorporated in the soil. But the soundness of these arguments still needs experimental proof. As regards argument No. 1 above, viz. the rapidity of composting, it is of advantage only in some cases, e.g. in the disposal of town refuse by municipalities. But if the process involves simultaneously heavy losses of nitrogen, the financial loss involved thereby is a factor which cannot be ignored. In the case of the private farmer, the rapidity of decomposition may prove a serious disadvantage, since the farmer requires his manure only once in six months and in many areas only once a year for application to land. He will be faced with the problem of how best to store the manure without loss of manurial value, if the composting be finished several months in advance of the date when he may be requiring it.

As regards argument No. 2 above, viz. the degree of decomposition to which a material should be subjected before it is fit for application to land, this is a question on which divergent views are held and convincing experimental evidence is lacking. There is no experimental evidence to show that it is necessary to decompose a material to the ultimate stage of a dark-brown, friable powder before it is fit for application to land. The earlier experiments regarding the unsuitability of straw for direct application to land have been found to be due to the wide C : N ratio of such material, and composting has been found to narrow the above ratio. It has been claimed that soil organic matter has

an approximate C : N ratio of 10 : 1 and that ærobically prepared composts finally approach this ratio and hence are in a fit condition to be applied to land. Waksman in his book on 'Humus' points out that materials of C : N ratio near 15 : 1 do not immobilize soil nitrogen but tend to increase the available nitrogen in the soil. The above ratio is apparently much wider than the ratio of 10 : 1 aimed at in the ærobic methods of composting.

Field experiments have been proceeding at Rothamsted (England) for some years past wherein the compost prepared by the Adco method with a C : N ratio near 11 : 1 has been compared with the direct application to the land of straw and the minerals used for compost preparation, the C : N ratio of the uncomposted materials being near 30 : 1. The levels of nitrogen, phosphoric acid and potash applied in the two cases are the same. The experiments have been proceeding only for the last five or six years, but the results obtained so far show that the uncomposted materials give as good crop responses as the compost.

The above would show that the C : N ratio of a compost material is not the only criterion for judging the suitability of its application to land. On the other hand, a better criterion would be the presence of readily available nitrogen in the material enough to supply the 'nitrogen factor' or the nitrogen requirements of the easily decomposable fractions in the raw material. If for financial or other reasons it is not found advisable to add mineral supplements in order to increase the available nitrogen in the material, the process of fermentation (or composting) has to be resorted to in order to remove the readily oxidizable constituents of the raw material. This should be carried out to such an extent as not to lose any appreciable quantity of the nitrogen originally present in the raw material. Such losses usually fall on the readily available groups such as ammoniacal or nitrate nitrogen and hence greatly lower the manurial value of the product when put on the field. Considered in this light, the hot fermentation method not only conserves a greater portion of the original nitrogen, but also minimizes the loss of the best portion of it, from the manurial point of view.

The question whether composting could be avoided altogether and the raw materials can be directly put on the land requires further and large scale experimentation before a definite answer could be given. The Rothamsted experiments indicate that under certain conditions, it is possible to do so, especially when the raw materials are supplemented by suitable quantities of nitrogenous artificials. Somewhat similar results have been obtained by the Tocklai Experimental Station in some of their experiments on tea*. But the experiments need repetition at a number of other centres in India where climatic and soil conditions and crops raised are different. In both the Rothamsted and Tocklai experiments, water supply has not been the limiting factor, and it is well known that with satisfactory water supply, partially decomposed materials can be safely put on land. Unfortunately, water supply is a serious limiting factor in most areas of this country.

It would also be interesting to know whether the Rothamsted results with straw could be duplicated in this country, using cattle dung and urine as the nitrogenous supplement to straw in place of artificials. The availability of

* Private communication.

nitrogen in the dung *plus* urine starter would be lower than in artificials and it would be useful to know whether with such a supplement the undecomposed raw materials when directly put on the land would prove beneficial to plant growth. In such cases it may be found necessary to remove the readily oxidizable constituents of the raw materials by a preliminary process of fermentation, at least to the extent secured in the hot fermentation process.

While our knowledge of the conditions under which undecomposed materials could be safely put on land to serve as manure for a crop already on the land or about to be sown in is still indefinite, the field trials that have been carried on with hot fermented manures have shown that they can be safely applied to land at any time, with beneficial results.

In addition to the larger recovery of manure and of nitrogen obtained by the hot fermentation method, this method possesses certain important advantages to the farmer from the practical point of view, namely in relation to labour and water requirements. The question of water requirement has been dealt with in detail in an earlier communication [Acharya, 1939] and it was shown therein that the hot fermentation process requires only about a third of the water supply required by the ærobic method, since the mass is packed anærobically after six days in the former method and no further additions of water are made. Water supply is a serious and in some cases a costly problem in vast areas of this country, e.g. in the Central Provinces, Deccan, etc. In such areas the hot fermentation method would prove particularly useful.

Secondly, the hot fermentation process requires much less labour than the ærobic method, since in the former case there are no periodical turnings and waterings to be given. No attention has to be paid to the compost after once it is packed in the trenches and closed up after a week, till the compost is actually required for application to land. As such, the farmer obtains the compost at a much lower cost and with much lesser trouble than in the case of the ærobically prepared compost. Estimates show that the labour charges for making one ton of compost by the hot fermentation method comes to about 8 As., when working on the large scale, whereas in the ærobic method the charges amount to about three or four times as much.

The hot fermentation system of composting, therefore, appears to be peculiarly suited to the conditions existing in this country.

Summary and conclusions

A comparison of the hot fermentation and ærobic systems of composting was made under controlled conditions: (I) with *ragi* straw in jars on a laboratory scale; (II) with *ragi* straw on the large scale in trenches and overground heaps; (III) with town refuse in concrete cisterns; and (IV) with town refuse on the large scale in trenches and overground heaps. Nightsoil, cattle dung *plus* urine and a mixture of mineral salts consisting of ammonium sulphate, calcium carbonate and superphosphate were used as starters for composting. Different modifications of the ærobic and hot fermentation methods, such as carrying out the composting in trenches and in overground heaps were tried. In the ærobic method, the heaps were turned over once in 15 days and watered to the necessary extent. In the hot fermentation method, the compost lots, generally in trenches, were allowed to ferment ærobically for six

days and then covered with a layer of mud paste and over it with loose earth. The comparison limited itself mainly to the efficiency of conservation of nitrogen, carbon and organic matter, since minerals such as calcium, potash and phosphates are not lost to a great extent, if the composting process be carried out with care.

The experimental data obtained showed :—

1. In all the cases examined, the hot fermentation method gave a much higher yield of manure, as measured by the organic matter contained, than the ærobic method, the ratio varying from $1\frac{1}{2}$ times to 3 times. In cases where the composting is carried out on plain ground or in unbricklined trenches, there is heavy contamination with extraneous soil, for which due correction should be made in the analytical figures.

2. The hot fermentation method conserved the original nitrogen of the refuse materials, in all the cases, examined to a greater extent than the ærobic method. The loss of nitrogen in the ærobic method was particularly great when nightsoil was composted with street sweepings and in some cases amounted to 50 per cent or more of the original amount.

3. The percentages of carbon and of organic matter in the final compost (after making a correction for the extraneous soil contamination) were also higher in the hot fermented composts than in the ærobically prepared composts.

4. As regards the relative percentages of nitrogen in the above two classes of composts, this varied with the initial C : N ratio of the refuse materials. Where the initial C : N ratio was wider than 30 : 1, the increase in conservation of organic matter by the hot fermentation process over the ærobic method was greater than the increase in conservation of nitrogen, with the result that the final percentage of nitrogen in the compost is lower in the hot fermentation method, though the total quantity of nitrogen recovered is greater in that method than in the ærobic. Where the initial C : N ratio is narrower than 30 : 1, the hot fermented composts possess a higher percentage of nitrogen in the final compost, along with a larger recovery of nitrogen in the total compost obtained.

5. The C : N ratio of the compost obtained by the hot fermentation method varies from 15 : 1 to 20 : 1, while that obtained by the ærobic method ranges from 11 : 1 to 15 : 1.

6. Carrying out the composting in trenches ensures a higher yield of manure and a better conservation of nitrogen than the use of overground heaps for composting.

7. Composts prepared by use of nightsoil, were generally richer in nitrogen and of better quality than composts prepared by use of cattle dung and urine as starters.

8. The addition of moderate quantities of earth promoted better decay of the compost and a better conservation of nitrogen, especially in cases where nitrogen-rich materials such as nightsoil were being composted.

9. The hot fermentation process requires only about one half to one third the water supply required by the ærobic methods and appears to be particularly suited to the ' dry ' areas of the country.

10. Labour charges in the hot fermentation process are only about a third or fourth of those necessary to carry out the ærobic method of composting, and the attention and supervision required in the former case are considerably less than in the latter case.

REFERENCES

Acharya, C. N. and Subrahmanyan, V. (1939). *Ind. J. Agric. Sci.* **9**, 741—4

Acharya, C. N. (1939). *Ind. J. Agric. Sci.* **9**, 817—33

Annual Reports of the Rothamsted Experimental Station (England) for the years 1935, 1936 and 1937

Ayyar, K. V. (1933). *Madras Agric. J.* **21**, 335

Hutchinson, H. B. (1918). *J. Agric. Sci.* (London) **9**, 92

Hutchinson, H. B. and Richards, E. H. (1921). *J. Min. Agric.* (*England*) **28**, 398

Waksman, S. A. (1936). '*Humus*', Williams & Wilkins Company, Baltimor (U. S. A.)

Waksman, S. A., Umbreit, W. W. and Cordon, T. C. (1939). *Soil Sci.* **47**, 37

Waksman, S. A., Cordon, T. C. and Hulpoi, N. (1939). *Soil Sci.* **47**, 83

IV. THE HOT FERMENTATION vs. POUDRETTE METHODS FOR THE DISPOSAL OF NIGHTSOIL

BY

C. N. ACHARYA, M.Sc., PH.D., F.I.C.

Department of Biochemistry, Indian Institute of Science, Bangalore

(Received for publication on 20 Nov. 1939)

IN a previous communication in this series [Acharya, 1940] the relative advantages of the hot fermentation and ærobic methods of composting were discussed, with special reference to the treatment of town wastes rich in nitrogen, such as nightsoil, and it was shown therein that a better conservation of nitrogen and organic matter was secured in the former method as compared with the latter. Very few municipalities, however, adopt at the present day either of the above systems of composting for the disposal of their nightsoil in spite of active propaganda in this direction by some of the Departments of Agriculture in India—especially those in Madras and Bombay. The method generally adopted by over 90 per cent of the municipalities in this country is that known as ' pitting ' or ' trenching ' nightsoil, carried out at nightsoil depots situated at some distance outside municipal limits. In this method, the nightsoil is let out into trenches three or four feet broad and equally deep, dug in the ground, and is then covered over with a layer of rubbish or more usually with earth. The Nasik Municipality has paid particular attention to the details of a proper system of trenching so as to avoid odours and flybreeding and to hasten the drying up of the material. The product so dried is usually designated as ' poudrette ' and sold as manure to the ryots.

The ' poudrette ' method of disposal of nightsoil has been in general use in municipalities in this country for the last five or six decades and is even now preferred to the method of ' composting ', since it is felt that the former method is simpler to carry out and requires less expense and supervision. But, unfortunately, this method of disposal brings little return to the municipalities. The annual income realized by sale of the poudrette in the trenches after a year of drying, amounts on the average to a few hundred rupees only as against the expense of several thousands per year incurred for the collection of nightsoil and street rubbish. This low income is partly attributed to the persistence of the smell of nightsoil in the poudrette, since the latter is more or less only dried nightsoil, and it is well known that the Indian ryot has a sentimental aversion to the handling of such a product [Leather, 1895]. It is also possible that during the process of poudrette-making, as ordinarily practised by municipalities, a good portion of the manurial value is lost from the nightsoil as may be inferred from a typical analysis quoted by Leather [1895] of a poudrette prepared in Cawnpore, viz.

TABLE I

Analysis of poudrette from Cawnpore

	Percentage
Moisture . .	2·64
Organic matter .	7·82
Earthy substance .	89·54
Nitrogen . .	0·468
Phosphoric acid .	0·499

In view of the prevalent custom of most municipalities in India, of converting their nightsoil into poudrette, it was considered advisable to compare the relative efficiencies of the poudrette method and the hot fermentation process of composting from the point of view of the conservation of manurial constituents and other factors such as hygienic requirements, cost of operation, net income to the municipality etc.

To start with, the writer would like to clear up a certain amount of indefiniteness which seems to persist even at present in the relative use of the terms ' poudrette ' and ' compost ', in relation to the treatment of nightsoil. Before the principles of compost making became clear as the result of the pioneering work of Hutchinson and Richards [1921], the term poudrette was indiscriminately applied to mixtures of nightsoil with other materials, either organic such as rubbish or inorganic such as soil or ash [Leather, 1895 ; Kelkar, 1909]. But now the term ' compost ' is generally applied to bulky organic materials which have undergone fermentation, usually by the addition of a nitrogenous starter. Since nightsoil is one of the best starters that could be used for this purpose, the term ' compost ' would properly apply to the product obtained by fermentation of bulky material such as street sweepings with the addition of nightsoil. The term ' poudrette ' is best restricted to the products obtained by dehydration of nightsoil either with dry earth or other materials such as ash, sawdust, lignite or by the action of heat [Bruttini, 1923].

Kinds of poudrettes.—Nightsoil can be converted into poudrette by one of several ways : viz. (1) by simple exposure to the sun in trenches, as in the Nasik system, with a thin covering of rubbish in order to prevent flybreeding ; (2) by the addition of woodash in shallow beds and thorough mixing, as in the Poona system [Kelkar, 1909] ; (3) by the addition of other drying agents such as powdered lignite, peat, sawdust etc. [Bruttini, 1923] or (4) by the effect of heat, along with the addition of chemicals such as chlorine, sulphuric acid etc. in order to remove the odour [Bruttini 1923]. Of these methods, systems 1 and 2 are simple and are easy of adoption by most municipalities in this country, whereas systems 3 and 4 require either special equipment or require materials in large quantities which are not easily available at most centres. Hence, in the investigations reported in the present paper, particular attention was paid to systems 1 and 2 only mentioned above.

POUDRETTE WITHOUT THE ADDITION OF ANY DEHYDRATING AGENT

Fifteen hundred lb. of nightsoil were led into trenches 2 ft. broad, 3 ft. deep and 5 ft. long. The nightsoil occupied a depth of 2½ ft. in the above trenches and was covered over loosely with a layer of the organic fraction of

street sweepings to a depth of about three inches. Fifty lb. of the organic refuse were used for the purpose. The experiment was carried out in duplicate and observations were made on the changes undergone in the system.

It was noticed that in about 48 hours there was rapid frothing and liquefaction of the mass, as evidenced by the nightsoil separating into a solid layer at the bottom and a thinner opalescent layer at the top. Bubbles of gas were given off from the mass, which burst open the rubbish layer at places ; this indicated that probably the lower layers of the mass were undergoing anærobic decomposition. The gases evolved were not analyzed, but tests with litmus and turmeric papers kept in the midst of the rubbish covering the top, showed the evolution of ammonia. This was confirmed by keeping a glass basin containing a known amount of standard dilute sulphuric acid on the rubbish, which absorbed considerable quantities of ammonia.

Portions of the upper liquid layer were taken out, after removing the scum at the top and were analyzed for ammonia on succeeding days, with the results shown in Table II. At the end of a week, the mass rapidly settled down and the upper opalescent liquid layer had slowly disappeared, due probably to seepage into the ground. It is evident that a good portion of the ammonia contained in this layer must have been lost either by diffusion into the air or by seepage into the ground.

TABLE II

Evolution of ammonia from nighsoil in trenches

Days from start	NH_3 N in 5 c. c. of opalescent upper layer mg.
2	3·6
3	5·2
4	6·8
5	4·6
6	3·2
7	2·1

The mass was allowed to remain in the trench for six months, at the end of which period it had dried completely and got into a powdery condition, partly mixed with the surrounding soil and the rubbish added at the top. The mass still smelt strongly of nightsoil, indicating that the process was more one of drying than of decomposition. The mass was scraped out, weighed and analyzed. The data obtained are shown in Table III. The analytical and sampling procedures were the same as reported in an earlier communication [Acharya, 1939]. In the present case also the resulting manure was contaminated by the addition of a considerable amount (about 94 lb.) of extraneous soil from the trench and outside ; a correction has been applied for this soil contamination according to the method reported in an earlier paper [Acharya, 1940] and the corrected figures are shown in column 4 of Table III.

TABLE III

Poudrette from nightsoil

Constituents	Taken at the start 1500 lb. N. S. +50 lb. rubbish (lb.)	Recovered at the end as poud-rette (lb.)	Recovery corrected for soil contami-nation (lb.)	Percent-age recoveny of consti-tuents.	Percent-age analysis of poud-rette (Column 3)
1	2	3	4	5	6
1. Dry matter . . .	337·7	308·8	213·7	63·28	..
2. Ash free organic matter .	256·6	133·8	132·6	51·68	43·33
3. Carbon . . .	154·9	76·8	76·2	49·20	24·87
4. Nitrogen . . .	17·11	7·13	7·08	41·38	2·31
5. Ash	81·1	175·0	81·1	100·00	56·66
6. P_2O_5	12·18	6·38	6·36	52·23	2·07
7. K_2O	6·86	3·94	3·72	54·23	1·28

The percentage recoveries of the original constituents given in column 5 of Table III, would show that nearly half the manurial constituents and in the case of nitrogen more than half are lost during the process of poudrette making, if the nightsoil be allowed to dry by itself without the addition of soil. Since the losses fall equally on the potash and phosphoric acid as well as on carbon and nitrogen, it is presumed that most of the loss should have been due to seepage into the ground of the liquid fraction formed in the preliminary liquefaction of nightsoil.

The percentage analysis of the final poudrette obtained is shown in column 6 of Table III. The data show that the manure is of good quality inspite of the heavy losses of manurial constituents during the process of poudrette making. The above losses are masked to a certain extent by the small recovery of manure obtained by this method. From 1500 lb. of nightsoil (fresh weight) only about 300 lb. of poudrette are obtained whereas the same quantity of nightsoil would yield about 2000 lb. of dry manure in the form of compost.

As regards the hygienic aspects of the method it was noticed that smell nuisance and flybreeding could not be effectively overcome by the loose cover of rubbish put on top of nightsoil.

NIGHTSOIL-EARTH POUDRETTES

In this method, 1500 lb. lots of nightsoil were let into trenches of the same size as in the preceding experiment, but the nightsoil was covered over

with a layer of dry earth six inches deep, instead of with a thin layer of organic refuse. When cracks appeared on the surface, more soil was added. It was found necessary to add 500 lb. of soil.

The sinking of the poudrette mass was more rapid in this case than in experiment I, probably due to the rapid absorption of water by the soil and its subsequent evaporation from the soil surface. The pressure of the soil layer at the top might have also helped to force down the liquefied portion of the nightsoil into the ground below, quicker. Flybreeding was effectively prevented in this method. The trenches were opened at the end of six months. Undecomposed nightsoil was still present in lumps of black masses and the poudrette smelt strongly of nightsoil. The mass was scooped out of the trench, along with the soil and was weighed and analyzed.

The analytical figures are summarized in Table IV. In addition to the 500 lb. of soil added to cover the nightsoil, further soil to the extent of about 200 lb. had got mixed as extraneous contamination. Due correction has been applied for this and the percentage recoveries of the constituents are given in column 5 of Table IV. These figures are similar to those given in Table III, though the recoveries are slightly better in the present experiment. The higher conservation of nitrogen is probably due to the absorption of ammonia by the soil layer at the top, which otherwise might have been lost into the atmosphere.

TABLE IV

Nightsoil-earth poudrette

Constituents	Taken at the start 1500 lb. N. S. + 500 lb. soil (lb.)	Recovered at the end as poudrette (lb.)	Recovery corrected for soil contamination (lb.)	Percentage recovery of constituents	Percentage analysis of poudrette on dry basis (Column 3)
1	2	3	4	5	6
1. Dry matter . . .	777·5	846·3	654·1	84·14	..
2. Ash free organic matter .	235·5	114·5	112·1	47·62	13·53
3. Carbon . . .	142·5	·8	58·6	41·14	7·07
4. Nitrogen . . .	16·75	8·71	8·61	51·41	1·03
5. Ash	542·0	741·8	542·0	100·00	87·64
6. P_2O_5	12·0	6·83	6·79	56·62	0·81
7. K_2O	7·5	3·99	3·55	47·43	0·47

The presence of a soil layer at the top improves the hygienic aspects of the method, but does not prevent the loss of the liquid portion of nightsoil by seepage into the ground and the consequent loss of manurial constituents. This can to a certain extent be avoided by interspersing thin layers of nightsoil and dry earth one over the other, but this would mean the addition of much larger quantities of earth than have been added in the present experiment and the consequent increased dilution of the manurial value of the poudrette.

The figures given in column 6 of Table IV would show that even when only 500 lb. of soil are added to 1500 lb. of nightsoil, which corresponds to a six inches layer of soil over a $2\frac{1}{2}$ feet layer of nightsoil, the manurial value of the resulting pouderette is reduced considerably. The product contains barely 1 per cent of nitrogen, 0·81 per cent of P_2O_5 and 0·47 perc ent of K_2O and is comparable to an ordinary type of compost ; the organic matter content is however lower in the former case. The yield of poudrette in the present instance is about 846 lb. from 1500 lb. of nightsoil (fresh weight). As observed already, about 2000 lb. of dry manure in the form of compost could be obtained from the same quantity of nightsoil. This would show that though the covering over of nightsoil with earth in poudrette-making secures an improvement over using a loose cover of organic refuse, this method cannot compare with the composting process, so far as the full utilization of the manurial constituents of nightsoil is concerned.

Nightsoil-ash poudrette

This system was given an extensive trial by the Poona Municipality in the beginning of this century, before the city was fitted up with underground sewerage. Kelkar [1909], however, remarks that in 1906 the system was given up by the municipal contractor in favour of what at present we would call a method of composting with town sweepings, presumably because the latter method gave a higher yield of manure from the same quantity of nightsoil.

Experiments were first carried out, in the present investigations, on the use of different proportions of nightsoil to wood-ash, and also on the use of coal-ash in place of wood-ash. Large quantities of coal ash are available at some centres, especially near railway workshops and factories. The preliminary experiments showed that when the amount of ash added was less than 40 per cent by weight of nightsoil (fresh) taken, the mass did not become solid. When one part by weight of ash was added to two parts by weight of nightsoil and the whole well mixed, the resulting product was a solid mass which easily dried when exposed to the sun for a day. The above proportion by weight corresponds roughly to a proportion by volume of equal quantities of wood-ash and nightsoil. The poudrette so obtained was ash-grey in colour and possessed, if at all, only a faint trace of odour. Even this trace of smell could be got over by the addition of about 10 per cent of powdered charcoal to the wood-ash.

Coal-ash was found to be equally satisfactory as a dehydrant and deodorizer for nightsoil ; but a serious drawback of coal-ash lies in the large amount

of iron and alumina contained in it. It is well known that a high proportion of these is inimical to plant growth and renders unavailable the phosphoric acid present in the manure as well as that already present in the soil.

TABLE V

Mineral composition of nightsoil ash, wood-ash and coal-ash.

Constituents	Nightsoil ash	Wood-ash.	Coal-ash
1. SiO_2 + acid insolubles	23·76	21·45	32·20
2. Fe_2O_3 + Al_2O_3	7·85	12·60	41·82
3. CaO	20·16	33·60	4·59
4. K_2O	10·11	5·30	0·92
5. P_2O_5	18·87	3·18	0·41

The relative composition of the ash constituents present in nightsoil, wood-ash and coal-ash is shown in Table V.

The preliminary experiments were followed by semi-large scale experiments carried out with 1000 lb. lots of nightsoil to which 500 lb. of wood-ash or coal-ash were added. The mixing was done with long handled spades in shallow wide trenches, bricklined and plastered inside. Immediately after mixing, the grey, solid mass was taken out and spread out to dry on bricklined platforms in the sun for a day or two ; after which, the bigger lumps were broken down with a wooden mallet and the manure was ready for being packed in bags for transport. From 100 parts of nightsoil (fresh weight) and 50 parts of ash, about 75 parts by weight of sun dry poudrette, containing about 10 per cent of moisture were obtained.

The chemical composition of the poudrettes obtained by the use of wood-ash and coal-ash respectively is given in Table VI. It will be noted therefrom that the coal-ash poudrette is equal to the wood-ash poudrette in regard to its content of organic matter and of nitrogen, but is much poorer in calcium, potash and phosphoric acid. Field trials with the above two types of poudrettes—to be reported in a subsequent communication—also confirmed the much superior manurial value of the wood-ash poudrette.

TABLE VI

Comparison of the chemical composition of wood-ash and coal-ash poudrettes (analytical figures on dry basis)

Constituents	Poudrette of night-soil with 50 per cent wood-ash	Poudrette of night-soil with 50 per cent coal-ash
	(Per cent)	(Per cent)
1. Ash free organic matter	18·51	18·84
2. Carbon	11·12	11·86
3. Nitrogen	1·32	1·30
4. Ash	81·49	81·16
5. K_2O	4·17	1·11
6. P_2O_5	2·84	1·01
7. CaO	24·24	4·31

The advantages of the ash poudrette method as compared with the earth poudrette method described in section on 'night-soil earth poudrette' above or the natural drying of night-soil examined in section on 'poudrette without the addition of any debyrating agent' above are: (1) the rapidity with which the process is finished, the ash-poudrette method requiring only two to three days, as against six to eight months needed in the other two cases; (2) the smaller amount of space required, the ash-poudrette method requiring only a shallow tank for mixing operations and a drying yard, whereas the other methods require long trench space; (3) the effective control of smell and flybreeding secured in the ash-poudrette method, so that the poudrette making unit can be situated quite near to towns instead of at a considerable distance from towns as in the other methods; this means considerable saving in cartage expenses; (4) the absence of a loss of manurial constituents in the ash-poudrette method due to volatilization or to seepage into the ground; (5) the considerable increase in the manurial value of the product obtained, due to the addtion of wood-ash which is rich in calcium, potash and phosphoric acid; (6) the greater yield of manure obtained by the wood-ash method, as compared to the other two methods. The use of coal-ash in place of wood-ash secures the advantages mentioned above, except No. 5. In fact, the manurial value is adversely affected due to the high concentration of iron and alumina present in coal-ash.

DISCUSSION

In assessing the relative merits of the poudrette vs.composting systems for the disposal of nightsoil, the following points have to be considered from the point of view of the municipality, viz. (*a*) hygienic considerations of smell

flybreeding and thorough destruction of noxious products ; (*b*) simplicity of operations and cost of process to the municipality ; and (*c*) the yield and quality of manure obtained and the net income obtainable by the municipality over and above the cost of processing. It will be convenient to consider these points separately.

(*a*) *Hygienic considerations*

The Nasik system of covering the nightsoil in trenches with a thin layer of rubbish (*katchra*) would appear to provide scope for flybreeding, unless stringent precautions are adopted to cover up immediately the portions where the nightsoil froths up and bursts the covering, especially in the initial stages. Since the process is mainly one of drying, the nightsoil does not undergo satisfactory decomposition and the resulting poudrette still retains an offensive odour, which becomes perceptible when the material is spread on the land ; the smell is carried in the direction of the wind over several miles even. It is this drawback which militates against the more widespread use of this material in our country—especially in areas where the farmer lives on his land.

The covering of the nightsoil trenches with a thick layer of mud six inches deep or more, satisfactorily prevents flybreeding. The microbial decomposition is greater in this case, due to the sinking down of the soil and its admixture with the nightsoil. But the admixture is not thorough, nor does ordinary earth by itself supply the carbonaceous material necessary for effective decomposition. As such, the decomposition is only partial in this case and the resulting poudrette still smells of nightsoil, though to a lesser extent than in the case where nightsoil is dried by itself. A marked disadvantage of adding earth to nightsoil, for purpose of drying, is the considerable dilution of manurial constituents produced thereby. This point will be dealt with in more detail under manurial considerations.

The ash-poudrette method is a distinct improvement over the other two systems, since wood-ash acts as a satisfactory disinfectant and also removes most of the smell. Flybreeding is successfully prevented. The main drawback of the ash-poudrette method, from the hygienic point of view, is that it does not secure a thorough destruction of the noxious products e.g. through a process of fermentation as the composting process does. The nightsoil ash system is more or less a mechanical mixture—at least for some weeks after its preparation ; and the addition of water is generally enough to separate the constituents and regenerate the undecomposed constituents of nightsoil.

From the above point of view, composting is the most hygienic method of disposal of nightsoil. The material is so thoroughly decomposed in the process, that the resulting product possesses generally a pleasant earthy smell and is devoid of any unpleasant odour. If the hot fermentation system of composting be adopted, flybreeding and smell are most effectively overcome.

(*b*) *Simplicity of operations and cost*

It is no doubt true that the present system of ' trenching ' the nightsoil, as adopted by most municipalities in this country is simple, but it is highly in efficient from the manurial point of view. With a little more control and

supervision, it is possible to compost the nightsoil with street rubbish in the same trenches as are used at present, with the result that a much greater quantity of manure of good quality could be obtained.

The preparation of wood-ash-nightsoil poudrettes, if properly organized, may prove to be the simplest of all methods of disposal of nightsoil. The process requires much less space and time than the ' trenching ' method and the cost of operation is proportionately decreased. It may be possible to cut down the time and space required for the ash-poudrette method still further, by carrying out the operations with simple machinery at higher temperatures, e.g. 60-70°C, such that a dry product is obtained straight from the ' mixer ', which is ready for immediate packing and transport.

But the ash-poudrette method suffers from one or two serious disadvantages, which detract greatly from the value of its simplicity and cheapness. In the first place, it requires large supplies of wood-ash which may not be readily available. About six to eight tons of wood-ash per day may be required to deal with the nightsoil collected in a town with a population of about 100,000. The Poona Municipality tried to overcome this difficulty [Kelkar, 1909] by burning the organic portion of street refuse and using the ash so obtained. But this method should be considered wasteful, since it involves the loss of organic matter and of nitrogen contained in such street refuse, which possess distinct manurial value on our soils which are poor in organic matter and nitrogen. It would be sounder economics to convert such organic street refuse into manure by a process of fermentation. As an alternative to the method of burning street refuse, for obtaining the ash contained therein, municipalities can have recourse to a systematic collection of house hold ash separately from the dustbins and subjecting this to a preliminary heating before using it for poudrette making. This method may prove practicable in some of the smaller municipalities. At other centres where coal-ash is available in large quantities, this may be used to supplement the available supplies of wood-ash.

(c) *Quantity and quality of manure and income to the municipality*

Table VII gives data comparing the chemical composition of poudrettes against composts of nightsoil with street sweepings. In assessing the relative merit of any one method of disposal of nightsoil in comparison with another, consideration should be paid not merely to the chemical composition of the manure prepared but also to the total quantity of it obtainable by the method in question. Thus, referring to the data presented in Table VII one would note that the poudrette obtained by simple drying of nightsoil in trenches with a thin covering of rubbish (Nasik system) is very satisfactory in its chemical composition and contains a higher percentage of nitrogen, organic matter and phosphoric acid than composts. But the amount of manure obtained by the method from 1000 lb. of nightsoil is only 270 lb., including the rubbish added and extraneous soil contamination, while the hot fermentation system yields over five times the above quantity of manure (on dry basis). The system adopted by most municipalities of covering the nightsoil in trenches with a heavy layer of soil, yields a larger quantity of manure, viz. 564 lb. than the Nasik system, but in this case the manurial constituents are very much diluted by the inert mass of soil added. In spite of the dilution, the

resulting poudrette contains about 1 per cent of nitrogen and 13·5 per cent of organic matter and should be considered as satisfactory for application to land. But the total quantity of manure obtained by this system is still only a third of what is obtainable by the best systems of composting and the chemical composition is definitely poorer.

TABLE VII

Comparison of the chemical composition and yield of poudrettes and composts

	Poudrette by drying nightsoil with a thin covering of rubbish.	Nightsoil-earth poudrette	Nightsoil-wood-ash poudrette	Compost from N. S. and street rubbish	
				Hot fermentation method	Aerobic method
	lb.	lb.	lb.	lb.	lb.
Yield of manure (dry wt. from 1,000 lb. fresh Night-Soil.	270	564	700	1,500	1,000
Percentage analysis of manure on dry basis	Per cent	Per cent	Per cent	Per cent	Per cent
1. Ash free orgnic matter .	43·33	13·53	18·51	31·85	28·89
2. Carbon . . .	24·87	7·07	11·12	18·01	14·98
3. Nitrogen . . .	2·31	1·03	1·32	1·13	0·99
4. Ash	56·66	87·64	81·49	68·15	71·11
5. P_2O_5	2·07	0·81	2·84	1·08	1·48
6. K_2O	1·28	0·47	4·17	1·06	1·48
7. CaO	..	..	24·24	9·12	12·77

The wood ash-poudrette method on the other hand has the attractive feature that it yields a good type of manure rich in lime, potash, phosphoric acid and nitrogen.

As will be seen from Table VII, the quantities of phosphoric acid, potash and calcium present in the ash-poudrette are two to four times as great as those ordinarily present in composts and the nitrogen percentage is slightly higher. As such it seemed worthwhile making a critical comparison of the economics of disposal of town wastes by the above two methods—on the supposition that the organic portion of street rubbish is incinerated to yield the ash required in the former method. The results of such a comparative

study are presented in Table VIII. Data for the preparation of coal-ash-nightsoil poudrettes are also included, though, as already pointed out, the manurial value of such poudrettes is much less—the reason for the inclusion being that large quantities of coal-ash are available as waste material at several centres.

TABLE VIII

Comparison of the economics of conversion of nightsoil into composts and ash-poudrettes

Data per ton of compost (50 per cent moisture) or per ton of poudrette (10 per cent moisture)	Compost of Night-soil with street sweepings.		Poudrette of Nightsoil with ash	
	Hot fermentation process	Aerobic method	Wood-ash	Coal-ash.
Refuse required.	lb.	lb.	lb.	lb.
Nightsoil	750	1,100	3,000	3,000
Street sweepings	1,250	1,650	...	...
Wood or coal-ash	...	...	1,500	1,500
	Re. A. P.	Re. A. P.	Re. A. P.	Rs. A. P.
Extra cost to the municipality in preparing compost or poudrette per ton of manure.	0 8 0	1 0 0	0 8 0	0 8 0
	Per cent.	Per cent.	Per cent.	Per cent
Plant nutrients per ton of manure (50 per cent moisture in composts and 10 per cent in ash poudrettes). N	0·57	0·49	1·19	1·17
P_2O_5	0·54	0·74	2·83	1·00
K_2O	0·53	0·74	3·75	1·18
CaO	4·56	6·38	21·82	3·88
Organic matter.	15·92	14·45	16·66	16·96
	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
Price of above nutrients at normal market rates for inorganic fertilizers viz.— Rs. 5 per unit of N (1 per cent per ton) ; Rs. 25 per unit of K_2O and P_2O_5 ; Re. 0·1 per unit of CaO ; Re. 0·05 per unit of organic matter.	6 12 0	7 8 0	25 8 0	12 8 0
Price of above nutrients calculating on the basis of 50 per cent availability of the nutrients.	3 6 0	3 12 0	12 12 0	6 4 0
Expected sale price per ton of manure	2 0 0 At Re. 1 per cartload ($\frac{1}{2}$ ton) of manure (50 per cent moisture)	2 0 0	5 0 0 Supplied by weight per ton (10 per cent moisture)	2 8 0
Profit over cost of preparation per ton of manure	1 8 0	1 0 0	4 8 0	2 0 0
	Tons	Tons	Tons	Tons.
Amount of manure that could be prepared in a municipality of 100,000 population.	12,000	8,000	3,000	3,000
	Rs.	Rs.	Rs.	Rs.
Annual income to municipality after deducting extra expenses incurred for manure preparation.	18,000	8,000	13,500	6,000
Approximate annual expenses of municipality of 100,000 population for collection and removal of nightsoil and street rubbish (excluding supervising staff).	36,000	36,000	36,000	36,000

In the data presented in Table VIII only the extra cost to the municipality in carrying out the composting or poudrette making is included. The costs of collection of refuse materials and their transport to the manure making depot are not included, it being assumed that these form part of the regular sanitary work of the municipality which is being carried out at present and will have to be continued in future, purely from considerations of hygiene, irrespective of the way in which the refuse materials are disposed off finally. In comparing the relative costs of processing assigned to poudrette making and to composting, it must be noted the poudrettes prepared contain only about 10 per cent of moisture, whereas the composts contain 40 to 50 per cent of moisture. Hence, on an equal dry-weight basis, the cost of processing in compost making would be almost double the figures given in Table VIII. Between the two systems of composting, the higher charges allotted to the ærobic method are due to : (*a*) the number of turnings that have to be given in that method and consequent increased labour charges ; (*b*) the extra water that has to be added in the ærobic method at each turning ; and (*c*) the larger amount of refuse material that has to be dealt with initially, to produce one ton of final compost, on account of the greater loss of organic matter in the ærobic method.

The content of plant nutrients contained in the different manures (Table VIII) are taken from Table VII, and the price per ton of manure has been calculated on the basis of the normal unit prices for the chief manurial ingredients such as nitrogen, potash, phosphoric acid and calcium contained in the corresponding inorganic fertilizers. The values so obtained represent only the upper limit, for it is well known that the nutrients present in bulky organic manures such as composts or farmyard manure are but partially available for plant growth and that only slowly. The residual value of an organic manure, however, is an important consideration for which due provision must be made in assessing the cost of that manure. Long duration experiments extending over several decades, carried out at Rothamsted and at Woburn [Rothamsted Report, 1932] with farmyard manure have shown that about 50 per cent of the nitrogen of farmyard manure is recovered in the crops and in the soil over a period of years, but the remaining 50 per cent is lost, either into the atmosphere or into the sub-soil. Corresponding field trials with composts in order to assess the nitrogen availability of different types of composts have not been made, but it may be assumed that in the case of composts prepared from nightsoil, the availability of nitrogen would be at least 50 per cent. Actual field trials carried out at Bangalore, over several seasons, have shown that such nightsoil composts and poudrettes give higher crop yields than farmyard manure.

The degree of availability of the other manurial constituents such as potash, phosphoric acid and calcium, present in composts, has not been determined, but taking on a rough average that all constituents are available to an extent of 50 per cent, the prices per ton of manure work out to Rs. 3-6-0 to Rs. 3-12-0 in the case of nightsoil compost, Rs. 12-12-0 for the wood-ash-poudrette and Rs. 6-4-0 for the coal-ash-poudrette.

But, in fixing the prices of the manures, due consideration must be paid to the cost of transport of the manure from the Municipal Depot to the ryot's land, probably several miles off. In order to provide for both the above

factors, the actual sale prices of the manures are fixed in Table VIII at about ½ to ⅓ of their intrinsic manurial value. Thus, the composts are priced at Rs. 2 per ton, i.e. at Re. 1 per cartload of half a ton, while the wood-ash-poudrette is priced at Rs. 5 per ton and the coal-ash-poudrette at Rs. 2-8-0 per ton.

The profit over the cost of processing, is found to be greatest in the case of the wood-ash-poudrette, being Rs. 4-8-0 per ton, as compared to Rs. 2 per ton obtained for the coal-ash-poudrette, Re. 1-8-0 per ton for the hot fermented compost and Re. 1 per ton for the aerobically prepared compost. But these profits have to be weighed against the respective total quantities of manure that could be prepared in any particular area. In a municipality with a population of 100,000 for instance, about 4,000 tons of nightsoil and 20,000 tons of street sweepings containing about 5,000 tons of organic refuse, may be expected to be collected per year. From this amount of refuse, it would be possible to prepare about 12,000 tons of compost (50 per cent moisture) by the hot fermentation process, 8,000 tons of compost (50 per cent moisture) by the aerobic method and only 3,000 tons of poudrette manure (10 per cent moisture) either with wood-ash or with coal-ash. Multiplying the profit per ton of manure by the respective quantity of manure prepared, we find that the greatest income to the municipality (Rs. 18,000 per year) could be expected by adopting the hot fermentation system of composting, followed respectively by the wood-ash-poudrette method (Rs. 13,000), the aerobic method of composting (Rs. 8,000) and the coal-ash-poudrette method (Rs. 6,000).

It will be interesting to compare the above incomes with the average expenses incurred by a municipality of the above size for the actual collection and transport of nightsoil and street rubbish (excluding the salaries of the supervising staff), which may be estimated at about Rs. 36,000 per year. Hence, by adopting the hot fermentation process of composting, it would be possible for the municipality to recoup about half of the expenses incurred for the collection of town refuse in its area, whereas by the wood ash poudrette method more than a third of the above expenses could be recovered. This income is in addition to what the municipality could obtain by a preliminary sorting out, from street rubbish, of products such as waste paper, rags, tins, leather, iron pieces, glass etc., which could be marketed separately and be made to yield a considerable revenue, especially in the bigger municipalities.

A greater income than the above could be obtained by a judicious combination of both the compost and ash-poudrette methods. It has already been pointed out in an earlier communication [Acharya, 1940] that though the hot fermentation process of composting secures a better conservation of nitrogen than the aerobic method, still about 20-25 per cent of the nitrogen is lost in the former case. This loss was attributed to the narrow C : N ratio of nightsoil (about 8 : 1) and of street sweepings in India (about 25 : 1), and, consequently, of a mixture of the two. It was pointed out also in the above communication that the loss could be minimized by widening the initial C : N ratio, which could be effected to a certain extent by decreasing the proportion of nightsoil : organic refuse : soil fraction below the ratio of 2 : 2 : 1 (by weight) used in the above experiments. This would mean the setting free of a portion of the nightsoil to be disposed off otherwise than by composting. The quantity of nightsoil so liberated could best be converted into wood-ash-poudrette.

It is, therefore, suggested that with a view to secure the fullest utilization of the manurial constituents present in town wastes (including nightsoil, house-hold ash and street sweepings) with the least loss of those constituents during the process of conversion into manure, it would be of advantage to a municipality to adopt and carry on both systems of manure-making side by side, viz. preparation of ash-poudrette and composting with street sweepings. The quantity of nightsoil used for poudrette making would depend on the quantity of ash, (household ash or coal-ash) available in the locality ; and the remaining bulk of nightsoil could be composted with street sweepings, preferably in a proportion of not less than one part by weight of nightsoil for every two parts of the ' organic ' fraction and one part of the ' soil ' fraction of street sweepings.

An objection sometimes raised against the adoption of the composting procedure is that it requires too much of space and time. But this difficulty will not arise in those cases (forming over 90 per cent of the municipalities in India) where the ' trenching ' (or ' pitting ') system is at present being adopted for the disposal of nightsoil, since the operations of composting could be carried on in a fraction of the trench area used at present and in a much shorter time. But in the case of densely populated urban areas of big cities, provision of enough space for composting purposes may offer practical difficulties. In such cases, it is possible to minimize considerably the space and time required for composting by carrying on the process in closed cells at a rapid rate in about 15 days) with the help of suitable mechanical devices, as in the Hyganic Process recently adopted by the Kensington Borough Council [Anstead, 1939] for dealing with its town refuse. But the relative economics of such mechanized processes, as compared to the simpler types of composting or poudrette making described in this paper, require further and more detailed examination, especially under Indian conditions of labour and market prices for organic manures, before the adoption of such mechanized systems could be recommended.

Summary

1. A critical study has been made of the different methods of poudrette preparation, e.g. by use of (*a*) nightsoil without the addition of earth ; (*b*) nightsoil *plus* earth and (*c*) nightsoil *plus* ash, in comparison with the methods of composting, with special reference to : (*a*) hygienic considerations ; (*b*) manurial value of the products obtained, as revealed by chemical composition ; (*c*) cost of operation and (*d*) total income obtainable by a municipality by adopting the process.

2. It is found that the drying of nightsoil by itself involves heavy losses of nitrogen, organic matter, phosphoric acid and potash, due to liquefaction of nightsoil and seepage of the liquid portion into the ground. The addition of dry earth decreases the losses to some extent, but as considerable quantities of earth are required, the resulting product of nightsoil with earth is low in manurial constituents.

3. The preparation of wood-ash-nightsoil poudrettes has several features to commend it, from the hygienic and manurial standpoints, and is a promising method of disposal of nightsoil. The operations can be carried out in a compact plant, quite rapidly, saving space and time and yielding a product

of high manurial value, which could be readily transported and sold over a wider area than compost.

4. The preparation of wood-ash-nightsoil poudrettes, however, suffers from some serious drawbacks, viz. (*a*) the difficulty of obtaining enough supplies of ash, and (*b*) the fact that the method does not solve the problem of a satisfactory disposal of street rubbish. The total yield of manure obtained by composting street rubbish with nightsoil is nearly twice as much, on the dry basis, as is obtainable by the conversion of nightsoil into the ash poudrette; and the net income to the municipality by adopting the composting process is nearly $1\frac{1}{2}$ times as much as in the other case.

5. With a view to secure the advantages of both systems, it is recommended that the system of poudrette making from nightsoil and wood-ash may be adopted to the limit of the local availability of wood (or house-hold) ash and that the remaining bulk of nightsoil may be composted with street rubbish.

REFERENCES

Acharya, C. N. (1939). *Ind. J. Agric. Sci.* **9**, 817

———————— (1940). *Ind. J. Agric. Sci.* **10**, 448

Anstead, R. D. (1939). *Trop. Agric. (Trinidad)* **16**, 206

Bruttini, A. (1923). Uses of waste materials. P. S. King & Son Ltd., London

Hutchinson, H. B. and Richards, E. H. (1921). *J. Min. Agric. (London)* **28**, 398

Kelkar, G. K. (1909). *Bull.* **34**, *Dept. Agric., Bombay*

Leather, J. W. (1895). *Agric. Ledger (India)*, **16**

Nasik system of pitting nightsoil—Leaflet issued by the Nasik Municipality (Bombay Province)

Rothamsted Experimental Station (England), *Ann. Rept.* for 1932, 32

NOTES

NOTICE 1 OF 1940 (JANUARY, MARCH 1940)

THE following plant quarantine regulations and import restrictions have been received in the Imperial Council of Agricultural Reaserch. Those interested are advised to apply to the Secretary, Imperial Council of Agricultural Research, New Delhi, for loan.

LIST OF U. S. DEPARTMENT OF AGRICULTURE, BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE, SERVICE AND REGULATORY ANNOUNCEMENTS.

1. *Quarantine and other official announcements* :—
   Dutch Elm Diseas Quarantine Regulations—modifications.
2. *Summaries of plant quarantine import restrictions* :—
   (*i*) *Kingdom of Italy—Italian East Africa*—cotton restrictions.
   (*ii*) *Republic of Paraguay-Basic Legislation*—the digest.
   (*iii*) *Republic of Turkey*—Prohibited plant pests and diseases.
   (*iv*) *Colony and Protectorate of Kenya*—Government notice No. 468—addition of potatoes to the list of restricted seeds.
   (*v*) *Jamaica. British West Indies*—Import permit required for plant material.
3. *Service and Regulatory Announcements*—
   (*i*) *April—June 1939.*
   (*ii*) July—September 1939.
4. *List of Intercepted Plant Pests—1938.*

CHANGES IN NOMENCLATURE

WITH the transfer of the Imperial Agricultural Research Institute from Pusa to New Delhi it has been found necessary to alter the nomenclature of the 'Pusa' varieties. The improved varieties so far evolved at Pusa and others that may in future be bred at New Delhi will henceforth be known as 'Imperial Pusa' varieties. The number of the variety in each case will be preceded by the letters 'I. P.'. This nomenclautre will also be adopted for the milch herd of the Institute as well as for herbarium specimens and specimens of insects, fungi, etc. This change has been made to keep up the earlier association of the Institute with the word 'Pusa' and at the same time to distinguish the strains bred by the Imperial Department of Agriculture from those which may be bred by the Bihar Agricultural Department at their station at Pusa.

A list of the old and the new names of the varieties of crops under distribution is given below :—

Crop	Old name		New name	
Wheat	Pusa	4	I. P.	4
Do.	,,	12	I. P.	12
Do.	,,	52	I. P.	52
Do.	,,	80—5	I. P.	80—5
Do.	,,	111	I. P.	111
Do.	,,	114	I. P.	114
Do.	,,	120	I. P.	120
Do.	,,	125	I. P.	125
Do.	,,	165	I. P.	165
Barley	,, Type	13	I. P.	13
Do.	,, ,,	21	I. P.	21
Oats	,, B. S.	1	I. P.	1
Do.	,, B. S.	2	I. P.	2
Do.	,, Hyb.	C	I. P. Hyb.	1
Do.	,, ,,	G	I. P.	2
Do.	,, ,,	J	I. P.	3
Paddy	Pusa Type	9	I. P.	9
Do.	,, ,,	18	I. P.	18
Do.	,, ,,	24	I. P.	24
Do.	,, ,,	31	I. P.	31
Do.	,, ,,	52	I. P.	52
Do.	,, ,,	124	I. P.	124
Do.	,, ,,	129	I. P.	129
Do.	,, ,,	144	I. P.	144
Rahar	,, ,,	15	I. P.	15
Do.	,, ,,	24	I. P.	24
Do.	,, ,,	51	I. P.	51
Do.	,, ,,	64	I. P.	64
Do.	,, ,,	80	I. P.	80
Gram	,, ,,	2	I. P.	2
Do.	,, ,,	6	I. P.	6
Do.	,, ,,	17	I. P.	17
Do.	,, ,,	25	I. P.	25
Do.	,, ,,	28	I. P.	28
Do.	,, ,,	53	I. P.	53
Mung	,, ,,	58	I. P.	58
Do.	,, ,,	18	I. P.	18
Do.	,, ,,	23	I. P.	23
Do.	,, ,,	28	I. P.	28
Urid	,, ,,	36	I. P.	36
Do.	,, ,,	4	I. P.	4
Do.	,, ,,	6	I. P.	6
Do.	,, ,,	7	I. P.	7
Lentil	,, ,,	14	I. P.	14
Do.	,, Hyb.	11	I.P.	11
Peas	,, S.	111-86	I. P. Hyb.	1
Linseed	,, Type	29	I. P.	29
Do.	,, ,,	12	I. P.	12
Do.	,, ,,	121	I. P.	121
Linseed	Pusa H.	124	I. P.	124
Do.	,, H.	10	I. P. Hyb.	10
Do.	,, H.	21	I. P. Hyb.	21
Do.	,, H.	55	I. P. Hyb.	55
Do.	,, H.	68	I. P. Hyb.	68

Crop	Old name		New name	
Sesamum	Pusa Type	3	I. P.	3
Do.	,, ,,	7	I. P.	7
Do.	,, ,,	29	I. P.	29
Safflower	,, ,,	30	I. P.	30
Chilli	,, ,,	34	I. P.	34
Do.	,, ,,	41	I. P.	41
Do.	,, ,,	46—A	I. P.	46—A
Do.	,, ,,	51	I. P.	51
Hemp	,, ,,	3	I. P.	3
Do.	,, ,,	6	I. P.	6
Do.	New Hibiscus.		I. P. Sab.	5
Tobacco (*N. Tabacum*)	Pusa Type	28	I. P.	28
Do.	,, ,,	58	I. P.	58
Do.	,, ,,	63	I. P.	63
Do.	,, Hyb.	142	I. P. Hyb.	142
Tobacco (*N. rustica*)	,, Type	18	I. P.	18
Indian Hemp	,, ,,	1	I. P.	1

REVIEW

Supplement to Root Nodule Bacteria and Leguminous Plants, BY E. B. FRED, I. L. BALDWIN & E. MCCOY

THE authors have collected the references to the recent work and have listed the papers published from 1932, the date of publication of their monograph 'Root Nodule Bacteria and Leguminous Plants', upto 1938. A few papers which were overlooked in the authors' book in 1932 are also listed separately. The index is also supplemented by a list of scientific names of all plants cited in the original monograph and by an author index. No attempt is made in this supplement to interpret the results of the recent investigations. The supplement will be useful as a comprehensive list of references to workers in this field of research. [N. V. J.]

GIPD—S3—1000 IC of AR—9-7-40—750.

ANC

ORIGINAL ARTICLES

THE EFFECT OF DIFFERENTIAL IRRIGATION AND SPACING ON THE FIELD BEHAVIOUR AND QUALITY OF CAMBODIA CO 2 COTTON

BY

V. RAMANATHA AYYAR., L.Ag.

NAZIR AHMAD, M.Sc., Ph.D., F. Inst. P.

AND

N. C. THIRUMALACHARI B.Sc. Ag.

(Received for publication on 22 February 1938)

(With two text-figures)

Introduction

MORE than five lakhs of acres are being cropped under Cambodia cotton (*G. hirsutum*) in Madras province. Nearly 60 per cent of this area is being irrigated from water lifted from wells with a low water-table. Irrigation in such places forms an expensive item in the cost of production. Surprisingly enough, the cotton growers there go on irrigating their crop very frequently without considering the requirements of the plants. Such a practice, not only reduces their margin of profit, but also precludes them from making the best use of the limited supply of water available in the wells.

It was thought desirable to determine the optimum frequency of irrigation for a crop of Cambodia cotton and to study whether such frequencies would affect the qualities of fibres.

Material and methods

For this purpose experiments were conducted during 1932-35 on the cotton breeding station situated in Coimbatore district, which contains the highest acreage in the province under Cambodia cotton. Their particulars are described, for the sake of easy reference, under the following heads :—

(*a*) *Nature of the soil.*—In the trials conducted during the first two years, the soils were reddish loam but they were of different depths. In the first year, the kankar layer was below five feet, while in the second, it was within two feet at some places. The soil used in the third year was distinctly alkaline and heavy, with defective drainage. These soils could, however, be taken as fairly representative of the types of soil over which Cambodia cotton is being grown in that district.

(*b*) *Time of sowing.*—Generally this exotic cotton is usually sown in October-November soon after the onset of the north-east monsoon. It has, however, been found in the experiments carried out by the department a few years ago, that the yields increased by more than 30 per cent when sown in early September and this time of sowing was adopted for the experiments reported here.

(c) *Method of sowing.*—The cotton growers are in the habit of sowing the seeds broadcast and then forming channels and beds for irrigation. The Agricultural department found after certain trials that sowing in lines $2\frac{1}{2}$ to 3 feet apart facilitated intercultivation and picking operations, and began to advocate that method as superior. Since line sowing would mean the division of the land into ridges, and since formation of ridges and furrows would affect the quantity of water consumed by the crop, both the methods, viz. the farmer's practice of sowing and irrigating in beds, and the departmental advice of throwing the land into ridges and furrows three feet apart, were used for comparison. In the ridged series, however, two separate spacings of 4 in. and 9 in. between two consecutive holes were included. The average stand of plants in these spacings are given in the following statement.

Average number of plants in 1/100 acre plots

1932-33			1933-34			1934-35		
4 in.	9 in.	Beds	4 in.	9 in.	Beds	4 in.	9 in.	Beds
324	150	208	338	137	219	272	128	217

It might be mentioned that in the bed series, a neighbouring cotton grower was asked to sow and thin in the way he usually did, so that it might be thoroughly representative of the farmer's conditions.

(d) *Size of plots.*—The plots were of two sizes. For the measurement of water used in each irrigation, the area of the full plot was taken into account while for the comparison of yields, smaller area in each plot was marked out in the centre with the object of removing the effects of the borders. In the ridged plots, the plots used for irrigation were seven ridges wide with no outskirts. But for the collection of data of yields, the central three ridges alone were taken, leaving two ridges as outskirts on each side. In addition a length of 6 ft. was cut out at both extremities of the ridges with a view to eliminate the effects of extra spacing and watering. In the flat bed series, areas equal to those obtained in the ridged plots were marked out in each treatment for the study of yields.

The ultimate area secured for yields was 1·3 cents in the first year and 1 cent in the next two years as against 3·7 cents and 2·8 cents used for irrigational treatments in those years.

In all the three years plots with no irrigation were included in the tests for reasons given on the next page. In the first year, these plots were of the same size as others, but it was noticed that the width of two ridges left out at each side of the central experimental area was not enough to cut away the effects of lateral seepage from the irrigated plots. The plots were therefore made wider in the subsequent two years. There were nine ridges in such treatments, out of which three ridges on each side of the central three rows were rejected for the determination of yields.

(*e*) *Irrigation frequencies.*—When cotton is sown in October-November with the starting of the north-east monsoon, the young plants grow in an over-saturated soil till the middle of December, by which time the rainy period ordinarily terminates. Thence onwards, dry weather prevails till the middle of April. It is during this period that the crops suffer from insufficiency of soil moisture. If the deficiency is not made up by artificial irrigation, the plants shed their buds and even bolls, with the result that the yield per acre is reduced from 900—1,000 lb. of *kapas* obtained under irrigated conditions to 400—500 lb. normally recorded on unirrigated fields. The irrigational treatments were therefore confined to the above periods of drought. All the plots were treated alike from the time of sowing up to that period. The crops were just producing stray flowers at the time of the first irrigation.

The farmers of Coimbatore generally irrigate their Cambodia cotton once in 12—15 days. It was thought sufficient to compare irrigation frequencies one shorter and another longer than this interval. The three variants chosen were, watering (1) once a week, (2) once in two weeks and (3) once in three weeks. These were compared with a set of plots that were not irrigated after the rains. Such plots were designated as 'dry'. Fortunately no heavy rains were received during the experimental period and those that fell were in the form of drizzles and not of such a magnitude as to seriously affect the treatments.

It might be mentioned here that the changes in irrigation frequencies were preferred to the quantities of water used in each watering, because of the fact that a recommendation made with regard to intervals between two consecutive irrigations would be more easily understood and put into normal practice by the farmers than one involving differences in the amount of water used in each irrigation, especially when no easy contrivance to measure water was available with them.

(*f*) *Measurement of water.*—Inasmuch as irrigations were to be carried out by both furrow and bed systems at different intervals, and since the amount of water consumed each time would be affected by the intervals between two consecutive irrigations, it was deemed necessary to measure the quantities of water used in each irrigation in all the treatments. This was made possible by the installation of a Kents Lea recorder. In this arrangement, the water pumped out from the well was first allowed into a masonry cistern to which was connected, by means of a small tube at the bottom, a smaller cistern which contained the float of Lea recorder. This float moved up and down with the level of water in the delivery cistern. This movement was automatically recorded by a needle on a chart wound round a drum moving slowly by means of clock work. On the chart were marked, in thousands of gallons, the quantities of water flowing out of a right-angled V notch fixed at one end of the cistern. The water was then conveyed to the fields through cement channels with no loss of water by seepage along its course.

Arrangements were made to record the time taken for irrigating each treatment. The method adopted was to note with the aid of a stop-watch the difference between the time of entry of water into the first furrow or bed and that when the water was diverted from the last furrow or bed. The quantity of water consumed was calculated by multiplying the time taken for

irrigation by the rate of discharge as recorded during that period in the chart of the Lea recorder. To ensure that the watering done to each plot was of almost uniform depth at each irrigation, the following procedure was observed. In the furrow system the inlets were closed as soon as water reached the further ends, while in the bed system they were closed immediately the water was found to spread over the entire surface of the bed. It might be stated that this system was commonly practised by all the farmers and as such it needed no special effort to adopt.

(*g*) *Layout of treatments.*—The following 12 treatments made up of combinations of four irrigations and three spacings were compared.

Irrigations	Spacings
(*a*) No irrigation	4 in.
(*b*) Irrigation once a week	9 in.
(*c*) Irrigation once in 2 weeks	Broadcast
(*d*) Irrigation once in 3 weeks	in beds

Of these the two treatments—no irrigations with 4 in. spacings and no irrigation in broadcasted beds—were not included by mistake in the first year. The treatments were laid out in randomized blocks replicated four times during the first two years and three times in the third year.

During the course of the experiments some plants died as a result of the stem weevil (*Pempheres affinis*) attack in all the plots. It was therefore apprehended that the inequalities in stand thus brought about would have appreciably disturbed the final yields. The yield data were therefore adjusted to equal stand by means of covariance, but on comparing the standard error of the crude and adjusted yields (*vide* below) it was felt that no advantage would be gained by the use of adjusted yields. The crude yields themselves were used for the statistical analysis.

	Standard error of yields	
	Crude	Adjusted
	Per cent	Per cent
1932-33	9·6	12·0
1933-34	9·5	9·6
1934-35	13·3	12·6

(*h*) *Fibre-tests.*—These tests included the determination of the mean fibre-length, mean fibre-weight per inch and percentages of mature, half-mature and immature hairs and were carried out on samples of three seasons. The mean fibre-length was found by making one Balls Sorter and two Baer

Sorter tests. The mean fibre-weight per inch was found by weighing bunches of whole fibres on a sensitive quartz micro-balance. About 2,000 fibres in 14 to 20 bunches were weighed for each sample. The detailed technique of these tests is described in Bulletin Series A, No. 25, entitled ' Testing of Indian cottons for quality at the Technological Laboratory ', while the method for determining the maturity count of a cotton followed in these tests will be found in the Technological Bulletin, Series B, No. 20 entitled ' Fibre-maturity in relation to fibre and yarn characteristics of Indian cottons.'

(*i*) *Spinning technique and yarn tests.*—A full account of the spinning technique adopted in the laboratory, and details of machinery, settings, speeds, etc., are given in the Technological Bulletin, Series A, No. 25. Such specific details as the drafts, spindle speeds, front roller speeds, etc. for each sample will be found in the tables of spinning test results in the appendix . Each of the three counts of each sample was spun on ten bobbins and the following tests were made on each bobbin.

Description of tests	No. of tests
Lea strength and actual counts	5
Single thread strength and single thread extension	10
Turns per inch	10

The methods followed for carrying out these tests are given in the bulletin referred to above. Each test result given in the tables of spinning test results in the appendix represents the mean of 50 tests in the case of lea-strength and count, and 100 in the case of single thread strength, single thread extension and turns per inch. The tables of spinning tests results also contain the average values of temperature and relative humidity prevailing in the rooms during the spinning and testing of each yarn.

Evenness of a yarn was estimated by visual examination and expressed by means of a numeral in the spinning test tables. The number of neps present in a yarn was also counted at the same time as the yarn was examined for evenness. The count was made on 40 portions of yarn, each 3·6 inches long, ten portions being taken from a bobbin. Neppiness is expressed as the average number of neps per yard of yarn.

Results

The agronomic data are presented under two heads—water consumption and yields—while those concerning the fibre characters are furnished under three heads—graders' reports, fibre test results, and spinning test results.

(*a*) *Water consumption.*—These are dealt with under two sub-heads (1) total quantity of water consumed (Table I), (2) water used at each irrigations (Table II).

It will be seen from the table of analysis of variance given in Table IB that the block variances were significantly high in all the three years , and that notwithstanding them, those due to treatments were still greater in magnitude, signifying that the treatments showed distinctly different requirements of water. When they were scrutinized further, it was brought out that

TABLE I A

Average total quantity of water consumed by each treatment in acre-inches

Frequency of irrigation	1932-33				1933-34				1934-35			
	Ridge		Bed	Average	Ridge		Bed	Average	Ridge		Bed	Average
	4 in.	9 in.	Broad-cast		4 in.	9 in.	Broad-cast		4 in.	9 in.	Broad-cast	
1 week	14·6	14·7	16·1	15·1	18·6	19·5	19·5	19·2	16·9	16·8	15·2	16·3
2 week	9·2	8·7	10·3	9·4	11·1	10·3	10·9	10·7	9·0	9·5	9·2	9·3
3 week	6·3	6·2	7·5	6·7	7·1	7·2	7·4	7·2	5·9	5·7	5·6	5·7
Average	10·0	9·9	11·3	10·4	12·2	12·3	12·6	12·4	10·6	10·7	10·0	10·4
Area of each plot	3·7 cents				2·8 cents				2·8 cents			

TABLE I B

Summary of the analysis of variance

Due to	1932-33			1933-34			1934-35		
	D. F.	Mean square	Value of *P*	D. F.	Mean square	Value of *P*	D. F.	Mean square	Value of *P*
Blocks	3	9·42	< ·01	3	13·0209	< ·01	2	1·7159	< ·01
Treatments	8	57·91	< ·01	8	114·9502	< ·01	8	65·7113	< ·01
Irrigations	2	220·68	< ·01	2	458·0430	< ·01	2	260·1990	Between ·05 & ·01
Spacings	2	7·32	< ·01	2	0·4146	> ·05	2	1·1309	
Irrigation and spacing	4	1·82	> ·05	4	0·6716	> ·05	4	0·7576	> ·05
Error	24	1·163	...	24	0·4743	...	16	0·2563	...

Comparison of mean values per plots

Item	Treatment means			Critical difference	Conclusion	Treatment means			Critical difference	Conclusions	Treatment means			Critical difference	Conclusions
	1 week	2 week	3 week			1 week	2 week	3 week			1 week	2 week	3 week		
Between irrigations	15·1	9·4	6·7	0·91	1 week > 2 week > 3 week	19·2	10·7	7·2	0·58	1 week > 2 week > 3 week	16·3	9·3	5·7	0·51	1 week > 2 week > 3 week
	4 in.	9 in.	B. cast			4 in	9 in.	B. cast			4 in.	9 in.	B. cast		
Between spacing	10·0	9·9	11·3	0·91	(4 in. = 9 in.) < Broad-cast	12·2	12·3	12·6	0·58	(4 in. = 9 in.) = Broad-cast	10·6	10·7	10·0	0·51	(4 in. = 9 in.) > Broad-casts
	Ridge	Bed				Ridge	Bed				Ridge	Bed			
Ridge vs. Bed .	10·0	11·3	...	0·79	Ridge < Bed	12·3	12·6	...	0·50	Ridge = Bed	10·6	10·0	...	0·44	Ridge > Bed

the differences in the frequencies of irrigations were more responsible for the differences than the changes in spacing, and that there was no interaction between spacing and irrigation frequency. As one should expect, 'one week' irrigation consumed the highest amount of water, while that done once in three weeks was the least, the differences between the three treatments being statistically significant in all the three years. When the effects of spacing were analysed, the behaviour was not consistent. In the first year broadcasted plots required more water, while in the third year both 4 in. and 9 in. spacings consumed more. In contrast to this, no difference was manifested between 4 in. and 9 in. spacings themselves. It is pointed out that the spacings by themselves were not responsible for the differential behaviour. Since 4 in. and 9 in. spacings were adopted in ridge method of planting as distinguished from broadcasting done in beds, it was plain that the method of irrigation had a greater influence for the causation of differences. Analysis of actual data for ridges vs. bed confirmed it. It was found that in the first year the bed method of irrigation consumed more water and in the third year the 'ridge' method used more. There was, however, one more point to be considered in this connection. In the first year (1932-33) the ridges were formed by mistake along the slope with the result the irrigations were more quickly done. This drawback robbed the data of that year of their significance. When the result of the other two years alone were scrutinized, it was found that ridge method of irrigation did not really reduce water consumption as is often claimed. On the other hand, it tended to increase as in 1934-35.

If the data of water consumed at each irrigation (Tables II A and II B) were examined, it was observed that the intervals between consecutive irrigations affected the quantity of water used each time ; the weekly irrigated plot utilized less water at each irrigation than that watered once in two or three weeks. This finding was to that extent in harmony with normal expectations. On closer scrutiny, it was noticed that the relationship between irrigation frequency and water consumption at each irrigation was not rectilinear. The average consumption in the plots irrigated once in two weeks was not double of that in the weekly irrigated, but was much less, the difference, however, being statistically significant. In the plots watered once in three weeks, the requirement was only a little more than in the two-week plots. In fact the differences were within the limits of statistical significance in all the years under study, showing thereby that the significant differences, obtained in the total quantities of water referred to previously, was more the effect of differences in the number of irrigations given than the actual water used each time.

The spacings had not caused significant differences in the average water consumption except in 1932-33, when the ridged plots recorded lower consumption, but much significance could not be attached to this finding for reasons mentioned already.

Examination of figures for individual irrigations revealed further that the water requirements tended to increase with the advance of summer (Fig. 1).

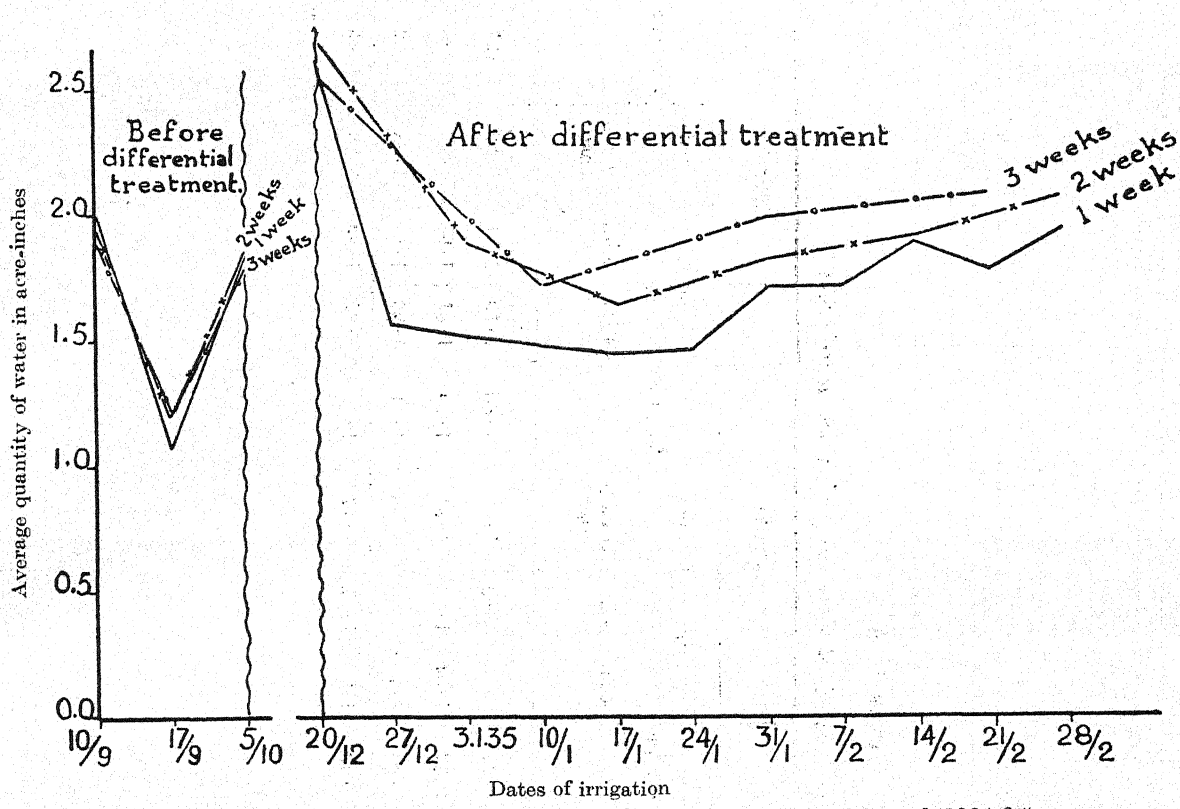


FIG. 1. Average quantity of water consumed by plots as the season advanced (1934-35)

(*b*) *Yields.*—The data of yields of the different treatments are given in Table III A. The statistical analysis of the results of the first year (Table III B) showed that the variance due to treatments was within the limit of significance. They were not therefore considered. On the examination of the data of the other two years it was seen that the unirrigated plots yielded only 489 and 474 lb. as against 759 and 641 lb. recorded on the average in the respective years by irrigated plots. These increases of 58 per cent and 35 per cent were statistically significant showing thereby the distinct advantage in yield got by irrigation.

A point of some interest was the lower increase obtained in 1934-35 which had to be ascribed to the alkaline nature of the soil.

Amongst the three irrigation frequencies, plots irrigated once a week recorded the highest yields, those watered once in two weeks less and those done in three weeks the least. But the differences between them were significant only in 1933-34, and that too only between the one and two week frequencies. In both years, the yields of plots irrigated once in three weeks were practically equal to those of the fortnightly irrigated plots. It was obvious from these that the present practice of irrigating once a fortnight could be safely put off to once in three weeks.

TABLE II A

Average quantity of water consumed at each irrigation in acre-inches

Frequency of irrigation	1932-33				1933-34				1934-35			
	Ridge		Bed	Average	Ridge		Bed	Average	Ridge		Bed	Average
	4 in.	9 in.	Broad-cast		4 in.	9 in.	Broad-cast		4 in.	9 in.	Broad-cast	
1 week	1·22	1·23	1·35	1·27	1·55	1·63	1·63	1·60	1·69	1·68	1·52	1·63
2 week	1·54	1·45	1·71	1·57	1·84	1·72	1·81	1·79	1·81	1·91	1·85	1·86
3 week	1·56	1·56	1·88	1·67	1·77	1·80	1·86	1·81	1·96	1·92	1·88	1·92
Average	1·44	1·41	1·65	1·50	1·72	1·72	1·77	1·73	1·82	1·84	1·75	1·80

TABLE II B

Summary of analysis of variance

Due to	1932-33			1933-34			1934-35		
	D. F.	Mean square	Value of *P*	D. F.	Mean square	Value of *P*	D. F.	Mean square	Value of *P*
Blocks	3	0·2127	< ·01	3	0·27750	< ·01	2	0·06840	< ·01
Treatments	8	0·1868	< ·01	8	0·04720	< ·01	8	0·06225	< ·01
Irrigations	2	0·5202	< ·01	2	0·16140	< ·01	2	0·21105	< ·01
Spacings	2	0·2052	< ·01	2	0·01080	> ·05	2	0·02025	> ·05
Irrigation and spacing	4	0·0109	> ·05	4	0·00830	> ·05	4	0·00885	> ·05
Error	24	0·0229	...	24	0·01015	...	16	0·00837	...

Comparison of mean values per plot

Item	Treatment mean			Critical difference	Conclusion	Treatment mean			Critical difference	Conclusion	Treatment mean			Critical difference	Conclusion
	1 week	2 week	3 week			1 week	2 week	3 week			1 week	2 week	3 week		
Between irrigations	1·27	1·57	1·67	0·13	1 week < 2 week = 3 week	1·60	1·79	1·81	0·08	1 week < 2 week = 3 week	1·83	1·86	1·92	0·09	1 week < 2 week = 3 week
	4 in.	9 in.	B. cast			4 in.	9 in.	B. cast			4 in.	9 in.	B. cast		
Between spacing	1·44	1·41	1·65	0·13	4 in. = 9 in. < B. cast	1·72	1·72	1·77	0·08	4 in. = 9 in. = B. cast	1·82	1·84	1·75	0·09	4 in. = 9 in. = B. cast
	Ridge	Bed				Ridge	Bed				Ridge	Bed			
Ridge vs. Bed	1·43	1·65	...	0·11	Ridge < Bed	1·72	1·77	...	0·07	Ridge = Bed	1·83	1·75	...	0·08	Ridge = Bed

TABLE III A

Summary of crude yields in lb. per acre

Treatment	1932-33				1933-34				1934-35			
	Ridge		Bed	Average	Ridge		Bed	Average	Ridge		Bed	Average
	4 in.	9 in.	Broad-cast		4 in.	9 in.	Broad-cast		4 in.	9 in.	Broad-cast	
1 week	648	663	605	639	880	848	814	847	806	524	733	688
2 week	634	528	554	572	763	704	696	721	756	429	673	619
3 week	485	648	598	577	706	742	679	709	743	561	546	616
Dry	..	518*	..	..	445	456	543	481	519	363	539	474
Average	589	613	586	596	699	687	683	690	706	469	623	599

* This figure was omitted in the analysis of variance as its inclusion made the analysis nonorthogonal.

TABLE III B

Summary of the analysis of variance

Due to	1932-1933			1933-34			1934-35		
	D. F.	Mean square	Value of *P*	D. F.	Mean square	Value of *P*	D. F.	Mean square	Value of *P*
Blocks	3	558·65	> ·05	3	3508·99	< ·01	2	532·02	> ·05
Treatment	8	652·77	> ·05	11	2066·35	< ·01	11	1508·16	Between ·05 and ·01
Between irrigation	2	717·99	> ·05	2	1800·91	< ·01	2	367·52	> ·05
Between spacings	2	123·39	> ·05	2	43·44	> ·05	2	4436·94	< ·01
Dry Vs irrigation	...	...	...	1	17882·26	< ·01	1	4848·12	< ·01
Irrigation Vs. spacing	4	884·85	> ·05	6	193·14	> ·05	6	355·46	> ·05
Error	24	386·95	...	33	267·09	...	22	486·38	...

Comparison of mean values

Item	Treatment mean			Critical difference	Conclusions	Treatment mean			Critical difference	Conclusion	Treatment mean			Critical difference	Conclusion
	1 week	2 week	3 week			1 week	2 week	3 week			1 week	2 week	3 week		
Between irrigations	639	572	577	80	None significant	847	721	709	85	1 week > 2 week = 3 week	688	619	616	135	1 week = 2 week = 3 week
	4 in.	9 in.	B. cast			4 in.	9 in.	B. cast			4 in.	9 in.	B. cast		
Between spacings .	589	613	586	80	Do.	699	687	683	73	4 in. = 9in. = B. cast	706	469	623	117	4 in. = B. cast > 9 in.
						Dry	Irri.				Dry	Irri.			
Dry Vs. irrigation	...	...	...	...	...	481	759	...	69	Irri. > dry	474	641	...	110	Irri. > dry
	Ridge	Bed				Ridge	Bed				Ridge	Bed			
Ridge Vs. bed .	601	586	...	69	Do.	693	683	...	64	Ridge = Bed	588	623	...	101	Ridge = Bed

Changes in the method of irrigation were not able to cause marked differences in productivity. Variations in spacing, however, were able to cause significant differences in one year. In 1933-34, 4 in. and 9 in. spaced plots were practically equal, while in the next year the difference brought about by closer spacing was markedly favourable in the ridged plots. It could be deduced from the above that in alkaline soil, the use of a higher seed rate would prove more profitable.

(*c*) *Grader's valuation reports.*—The grader's valuation reports on these samples of Cambodia Co 2 grown with different amounts of irrigation in the three seasons, 1932-35 are given in Table IV.

(*d*) *Fibre test results.*—The results for mean fibre-length as found by the two methods, mean fibre-weight per inch and maturity percentages are given in Table V.

(*e*) *Spinning test results.*—The 1932-33 and 1933-34 samples were all passed through the porcupine, crighton (twice), hopper, scutcher (3 times), card, drawing (2 heads), slubber, inter, rover and spun from single hank roving on ring frame No. 1. The spinning master's report on each sample is given in the appendix . Only fibre tests were carried out on the 1934-35 samples as they were not available in sufficiently large quantities for spinning tests.

Discussion

(*a*) *Agricultural conditions and yield.*—It was made clear in the foregoing pages that under the conditions obtaining at the Cotton Breeding Station Coimbatore, irrigating Cambodia cotton from December onwards improved the yields, but the rate of increase was not directly proportional to the increase in the irrigational frequency. It would be, therefore, necessary to determine under such conditions the stage at which the irrigation would become unremunerative. The extra yields secured in the last two years as a result of irrigations were converted into monetary values and compared with cost incurred in irrigations, and the results were set out in Table VI. It was seen there that irrigation done once in three weeks was more remunerative than irrigating once a week or once in two weeks, in spite of their recording higher yields.

It could not, at the same time, be said that the three-week irrigation would always be the most paying, since it was not tested here whether a still lower frequency would result in a better monetary return. This point gained some strength from the performances of some treatments tested in 1935-36. A few experiments carried out in that year indicated that two irrigations timed once in early January and another in early February were as productive as irrigations given systematically every three weeks. These are to be tested further. Again it could not be said from the data presented here whether the quantity of water applied at each irrigation was the optimum. The consumption per irrigation varied in the present experiments from 1·22 acre-inches in 1932-33 to 1·96 acre-inches in 1934-35. This dosage would normally be considered as light. It might be that a heavier irrigation would alter the frequency, and thereby the ultimate gain to the cultivator as well.

It would be useful now to consider the observations recorded here in the light of the data obtained in 1935-36 on the movement of soil-moisture. In that year moisture determinations were made periodically in the first, second and third foot layers of irrigated and unirrigated plots. The data relating to dry plots and plots irrigated once in three weeks are given in Fig. 2 together with

TABLE IV A

Grader's report for Cambodia Co 2 for 1932-33 season

	4 inch spacing				9 inch spacing			Broadcast		
	Dry	1 week	2 weeks	3 weeks	1 week	2 weeks	3 weeks	1 week	2 weeks	3 weeks
Contract valued under	Broach	Broach	Broach	Broach	Broach	Broach	Broach	Broach	Broach	Broach
Class	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine
Colour	Creamy	Creamy	Creamy	Creamy	Creamy	Creamy	Creamy	Creamy	Creamy	Creamy
Staple length	1 in.	1 in.	31/32 in.	15/16 in.	1 in.	15/16 in.	31/32 in.	15/16 in.	1 in.	15/16 in.
Staple strength	Fair	Fair	Fair	Poor	Fair	Poor	Poor	Poor	Fair	Fair
Regularity	Fair	Fair	Fair	Fair	Fair	Poor	Fair	Poor	Fair	Fair
Valuation above or below contract rate	Rs. 60 on	Rs. 70 on	Rs. 60 on	Rs. 50 on	Rs. 70 on	Rs. 50 on	Rs. 55 on	Rs. 50 on	Rs. 70 on	Rs. 55 on
Basis	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200
Date of valuation	20-3-34	20-3-34	20-3-34	20-3-34	20-3-34	20-3-34	20-3-34	20-3-34	20-3-34	20-3-34
Remarks	...	...	...	Weak staple	...	Weak staple	Weak staple	Weak staple	...	...

TABLE IV B

Grader's report for Cambodia Co 2 for 1933-34 season

	4 inch spacing				9 inch spacing				Broadcast			
	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks
Contract valued under	Broach	Broach	Broach	Broach	Broach	Broach	Broach	Broach	Broach	Broach	Broach	Broach
Class	Fine	About fine	About fine	About fine	About fine	About fine	About fine	About fine	About fine	About fine	About fine	About fine
Colour	Creamy	Creamy	Creamy	Creamy	Creamy	Creamy	Creamy	Creamy	Very Creamy	Creamy	Creamy	Creamy
Staple length	29/32 in.	7/8 in.	29/32 in.	29/32 in.	7/8 in.	29/32 in.	29/32 in.	29/32 in.	7/8 in.	13/16 in.	29/32 in.	13/16 in.
Staple strength	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Weak	Fair	Fair
Regularity	Fair	Irregular	Fair	Fair	Irregular	Irregular	Fair	Fair	Irregular	Irregular	Irregular	Irregular
Value above or below contract rate	Rs. 30 on	Rs. 45 on	Rs. 50 on	Rs. 50 on	Rs. 45 on	Rs. 50 on	Rs. 50 on	Rs. 50 on	Rs. 20 on	Rs. 35 on	Rs. 45 on	Rs. 35 on
Basis	Rs. 210	Rs. 210	Rs. 210	Rs. 210	Rs. 210	Rs. 210	Rs. 210	Rs. 210	Rs. 210	Rs. 210	Rs. 210	Rs. 210
Date of valuation	24-10-34	24-10-34	24-10-34	24-10-34	24-10-34	24-10-34	24-10-34	24-10-34	25-9-34	24-10-34	24-10-34	24-10-34
Remarks	...	...	...	...	...	Harsh	...	...	...	...	...	...

TABLE IV C

Grader's report for Cambodia Co 2 for 1934-35 season

	4 inch spacing				9 inch spacing				Broadcast			
	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks
Contract valued under	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936	Broach A/M 1936
Class	Fine to superfine	Fine to superfine	Fine to superfine	Fine to superfine.	Nearly superfine	Fine to superfine	Fine to superfine	Fine to superfine	Fine to superfine	Superfine	Superfine	Superfine
Colour	Creamy-white	Creamy-white	Creamy-white	Creamy-white	Creamy-white	Creamy-white	Creamy-white	Creamy-white	Creamy-white	Creamy-white	Creamy-white	Creamy-white
Staple length	3/4 in.	13/16 in.	13/16 in.	Nearly 7/8 in.	7/8 in.	7/8 in.	7/8 in.	7/8 in.	7/8 in.	7/8 in.	7/8 in.	13/16 in.
Staple strength	Moderate	Moderate	Slightly Better than dry sample	Good	Good	Good	Good	Good	Good	Good	Good	Moderate
Regularity	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular
Value above or below contract rate	Rs. 55 on	Rs. 60 on	Rs. 65 on	Rs. 70 on	Rs. 68 on	Rs. 70 on	Rs. 72 on	Rs. 65 on	Rs. 70 on	Rs. 70 on	Rs. 67 on	Rs. 65 on
Basis	Rs. 200	Rs. 220	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200	Rs. 200
Date of valuation	10-9-35	10-9-35	10-9-35	10-9-35	10-9-35	10-9-35	10-9-35	10-9-35	10-9-35	10-9-35	10-9-35	10-9-35
Remarks	...	...	Slightly yellow stain	More silky than previous tender	Sample knotty	Silky style	...	Sample somewhat knotty and neppy	...	Knotty	Slightly wasty	Not well ginned ; staple wasty

TABLE V A

Fibre particulars for Cambodia Co 2 for 1932-33 season

1. Fibre-length distribution (Balls Sorter): Mean group-length in eighths of an inch	Percentage									
	4 inch spacing				9 inch spacing			Broadcast		
	Dry	1 week	2 weeks	3 weeks	1 week	2 weeks	3 weeks	1 week	2 weeks	3 weeks
2	...	...	...	...	0·9	...	...	...	...	1·5
3	2·4	1·8	1·5	2·1	2·0	2·3	2·2	2·1	1·4	2·3
4	3·6	3·6	3·6	3·9	3·2	3·7	4·0	3·4	4·7	3·8
5	6·8	6·0	6·7	6·6	6·6	7·0	6·6	6·5	5·7	7·1
6	10·9	10·6	12·8	11·2	12·1	15·9	11·9	11·7	13·7	10·9
7	21·1	21·2	24·1	22·1	22·7	24·8	22·3	21·7	18·9	19·7
8	27·8	28·3	33·3	29·2	27·3	25·7	28·1	29·9	29·7	27·0
9	19·9	19·7	14·9	17·4	17·5	14·5	19·7	18·5	21·2	19·4
10	6·3	6·8	3·1	5·0	6·3	6·1	5·2	4·5	4·7	6·8
11	1·2	2·0	...	2·5	1·4	...	...	1·7	...	1·5
2. Fibre-length (inch):—										
(*a*) By Balls Sorter	0·93	0·94	0·91	0·93	0·92	0·90	0·92	0·93	0·93	0·93
(*b*) By Baer Sorter	0·90	0·91	0·93	0·90	0·90	0·93	0·90	0·94	0·92	0·92
3. Fibre-weight per inch (millionths of an oz.)	0·140	0·133	0·138	0·141	0·147	0·137	0·145	0·137	0·140	0·152
4. Maturity test results:—										
(*a*) Mature	53	61	58	65	54	58	56	65	58	67
(*b*) Half-mature	13	12	12	10	14	15	11	12	12	11
(*c*) Immature	34	27	30	25	32	27	33	23	30	22

TABLE V B

Fibre particulars for Cambodia Co 2 for 1933-34 season

	Percentage											
1. Fibre-length distribution (Balls Sorter) :— Mean group-length in eighths of an inch	4 inch spacing				9 inch spacing				Broadcast			
	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks
2	1·5	...	1·1	1·2	1·1	0·9	1·0	1·0	1·0	...	1·5	...
3	2·6	1·6	1·9	2·0	2·2	2·3	2·3	1·9	1·4	1·1	2·5	3·5
4	3·7	4·0	2·9	2·3	3·8	3·9	3·6	3·1	3·2	3·8	3·8	4·2
5	5·9	7·8	4·8	5·4	7·9	6·7	6·3	6·8	5·4	6·6	6·4	7·3
6	11·5	10·4	8·6	8·1	11·2	10·8	10·4	11·8	10·1	9·6	13·2	12·9
7	23·8	17·1	18·0	17·3	24·3	19·5	19·1	22·3	18·7	19·2	22·7	22·3
8	31·4	28·1	32·6	31·5	27·0	28·8	30·9	30·6	29·7	27·4	32·3	30·1
9	14·4	23·8	23·3	24·0	16·9	19·5	20·0	16·5	22·3	23·9	14·5	16·2
10	4·1	5·9	5·7	6·6	5·6	6·3	5·0	5·0	7·0	7·3	3·1	3·5
11	1·1	1·3	1·1	1·6	...	1·3	1·4	1·0	1·2	1·1	...	...
2. Fibre-length (inch) :—												
(*a*) By Balls Sorter	0·91	0·94	0·95	0·96	0·91	0·93	0·93	0·92	0·95	0·95	0·89	0·90
(*b*) By Baer Sorter	0·92	0·92	0·94	0·96	0·94	0·91	0·90	0·93	0·92	0·94	0·90	0·92
3. Fibre-weight per inch	0·134	0·137	0·141	0·136	0·134	0·138	0·131	0·138	0·130	0·138	0·137	0·135
4. Maturity test results :—												
(*a*) Mature	59	56	63	60	62	61	53	62	58	61	60	57
(*b*) Half-mature	10	14	15	12	13	12	16	13	15	13	13	13
(*c*) Immature	31	30	22	28	25	27	31	25	7	26	27	30

TABLE V C

Fibre particulars for Cambodia Co 2 for 1934-35 season

	Percentage											
1. Fibre-length distribution (Balls Sorter) :— Mean group-length in eighths of an inch	4 inch spacing				9 inch spacing				Broadcast			
	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks
2	1·1	...	0·6	0·7	0·8	...	0·8	0·6	1·0	...	...	1·0
3	1·6	3·1	3·3	2·1	1·6	1·3	1·9	3·0	1·4	1·5	2·0	2·3
4	2·7	4·4	4·1	3·2	4·1	2·6	3·3	5·0	3·5	4·0	2·3	4·2
5	4·6	6·1	6·5	6·3	7·5	5·3	6·2	7·9	8·0	8·3	6·2	6·2
6	9·8	11·6	11·1	11·6	12·7	11·0	12·0	14·7	19·0	15·4	14·1	15·6
7	21·9	26·9	22·2	22·4	29·4	30·2	24·0	24·4	34·2	27·1	24·5	28·3
8	29·3	32·1	32·6	33·7	33·3	33·2	29·8	27·9	23·9	28·3	31·0	31·7
9	18·7	13·7	16·3	15·8	9·0	13·4	16·9	12·7	7·3	12·0	15·0	9·7
10	7·6	2·1	3·3	3·5	1·6	3·0	4·3	3·2	1·7	3·4	4·9	1·0
11	2·7	...	...	0·7	...	...	0·8	0·6	...	...	...	...
2. Fibre-length (inch) :—												
(*a*) By Balls Sorter	0·95	0·90	0·90	0·92	0·88	0·92	0·92	0·88	0·86	0·89	0·92	0·87
(*b*) By Baer Sorter	0·92	0·88	0·90	0·94	0·88	0·90	0·88	0·88	0·90	0·86	0·88	0·90
3. Fibre-weight per inch (millionths of an oz.)	0·128	0·133	0·136	0·133	0·136	0·138	0·136	0 153	0·132	0·146	0·147	0·127
4. Maturity test results :—												
(*a*) Mature	44	48	40	41	46	45	46	49	50	54	45	39
(*b*) Half-mature	29	23	27	27	21	21	30	23	20	19	22	21
(*c*) Immature	27	29	33	32	33	34	24	28	30	27	33	40

TABLE VI

Treatment	1933-34				1934-35			
	Increase in the weight of *kapas* over dry plot	Value of the increase	Cost of irrigation	Profit or loss	Increase in the weight of *kapas* over dry plot	Value of the increase	Cost of irrigation	Profit or loss
	lbs.	Rs.*	Rs.**	Rs.	lbs.	Rs.*	Rs.**	Rs.
1 week	366	39	42	—3	214	23	42	—19
2 weeks	240	24—26	21	5	145	16	21	—5
3 weeks	228	24	14	10	142	15	14	1

* *Kapas* values at Rs. 30 per 280 lbs.
** Cost of single irrigation was taken at Rs. 3-8-0.

dates of irrigation and rainfall. It would be seen there that in the first foot, the fluctuations were wide and moisture levels were very much higher than in those in the unirrigated plots. They were high soon after each irrigation and least just prior to the irrigation. In the case of the readings of the second foot the variations were within narrow limits of the unirrigated plots and those of the third foot were practically identical with the second. It was evident from these that the irrigations affected mostly the first foot of soil. In other words it would appear that the chief purpose served by irrigation in Cambodia cotton would seem to be to preserve the moisture contents in the second and third foot layers and this function could be efficiently served by the irrigations given once in three weeks.

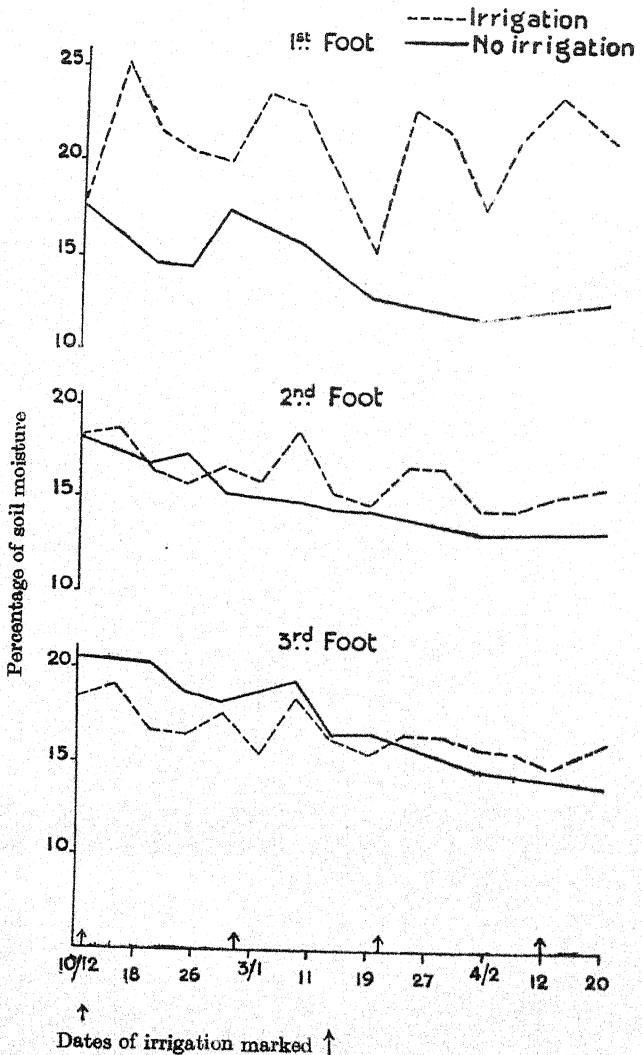


FIG. 2. Percentage of soil-moisture (irrigation experiment 1935-36)

(*b*) The results of the various fibre and spinning tests for these two seasons are summarized in Table VII.

TABLE VII

Particulars of irrigation experiments samples, 1932-33 and 1933-34

Coimbatore

Sample No.		Irrigation		Fibre-length (in.)		Fibre-weight per inch (10^{-6} oz.)		Maturity per cent		Total loss per cent		Neps per yard		Highest standard warp counts	
1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34
							9 in. spacing								
2120	2423	Once a week	Once a week	0·91	0·92	0·147	0·138	54	61	18·8	20·6	2·8	2·7	30	28
2123	2426	Once in 2 weeks	Once in 2 weeks	0·92	0·92	0·137	0·131	58	53	17·6	22·1	1·6	4·0	32	29½
2130	2429	Once in 3 weeks	Once in 3 weeks	0·91	0·92	0·145	0·138	56	62	18·3	19·4	2·9	4·0	29	31
2133	2432	Dry grown	Dry grown	0·92	0·92	0·140	0·134	53	62	18·8	24·5	3·3	4·8	32	29
							4 in. spacing								
2121	2424	Once a week	Once a week	0·92	0·93	0·133	0·137	61	56	17·0	20·9	1·5	2·5	30	28
2124	2427	Once in 2 weeks	Once in 2 weeks	0·92	0·94	0·138	0·141	58	63	15·9	21·7	1·5	4·3	32	29
2131	2430	Once in 3 weeks	Once in 3 weeks	0·92	0·96	0·141	0·136	65	60	18·4	19·5	3·2	4·7	30½	28
2133	2433	Dry grown	Dry grown	0·92	0·92	0·140	0·134	53	59	18·8	24·5	3·3	5·4	32	30
							Broadcast								
2122	2425	Once a week	Once a week	0·94	0·94	0·137	0·138	65	61	16·2	21·3	1·6	4·3	28	27
2125	2428	Once in 2 weeks	Once in 2 weeks	0·92	0·90	0·140	0·137	58	60	17·8	20·2	1·4	4·5	32	29
2132	2431	Once in 3 weeks	Once in 3 weeks	0·92	0·91	0·152	0·135	67	57	15·9	18·9	1·4	4·3	32	28½
2133	2434	Dry grown	Dry grown	0·92	0·94	0·140	0·130	53	58	18·8	25·2	3·3	5·3	32	29

TABLE VII—*contd.*

Percentage differences based on the dry-grown sample

Sample No.		Irrigation		Fibre-length (in.)		Fibre-weight per inch (10^{-6} oz.)		Maturity per cent		Total loss per cent		Neps per yard		Highest standard warp counts	
1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34	1932-33	1933-34
						9 in. spacing									
2120	2423	Once a week	Once a week	99	100	105	103	1	—1	...	—3·9	85	56	94	97
2123	2426	Once in 2 weeks	Once in 2 weeks	100	100	98	98	5	—9	—1·2	—2·4	48	83	100	102
2130	2429	Once in 3 weeks	Once in 3 weeks	99	100	104	103	3	...	—0·5	—5·1	88	83	91	107
2133	2432	Dry grown	Dry grown	100	100	100	100	...	...	...	...	100	100	100	100
						4 in. spacing									
2121	2424	Once a week	Once a week	100	101	95	102	8	—3	—1·8	—3·6	45	46	94	93
2124	2427	Once in 2 weeks	Once in 2 weeks	100	102	99	105	5	4	—2·9	—2·8	45	80	100	97
2131	2430	Once in 3 weeks	Once in 3 weeks	100	104	101	101	12	1	—0·4	—5·0	97	87	95	93
2133	2433	Dry grown	Dry grown	100	100	100	100	...	...	...	...	100	100	100	100
						Broadcast									
2122	2425	Once a week	Once a week	102	100	98	106	12	3	—2·6	—3·9	48	81	88	93
2125	2428	Once in 2 weeks	Once in 2 weeks	100	96	100	105	5	2	—1·0	—5·0	42	85	100	100
2132	2431	Once in 3 weeks	Once in 3 week	100	97	109	104	14	—1	—2·9	—6·3	42	81	100	98
2133	2434	Dry grown	Dry grown	100	100	100	100	...	...	...	...	100	100	100	100

The following conclusions are drawn from the results.

(1) *Mean fibre-length.*—The values of mean fibre-length of the 1932-33 samples are very nearly constant and do not show any significant variation with either the irrigation treatment or the different spacings. In 1933-34 while no significant differences in mean length are observed for samples grown with 9 in. spacing, for samples grown with 4 in. spacing the irrigated samples are found to be slightly longer than the unirrigated one, while in the case of the broadcast seed samples the mean fibre-length of the two irrigated samples is less than that of the unirrigated samples. These differences, however, are small and most probably within the sampling errors. It may, therefore, be concluded from the results of these tests, that neither the frequency of irrigation nor the different modes of sowing—each within the limits of this experiment—had any appreciable effect on the mean fibre-length of this cotton.

(2) *Fibre-weight per inch.*—The differences between the values of fibre weight per inch of the irrigated and the unirrigated samples are small. However, in a majority of cases the irrigated samples are found to have a somewhat higher hair weight per inch than the unirrigated samples. On the other hand, the mode of sowing had produced very little change in the hair weight per inch. We may, therefore, conclude that while the hair weight per inch of this cotton is independent of the mode of sowing employed in these tests, it shows a tendency to increase with the amount of irrigation given to the crop. In other words, with a more plentiful supply of water, there is a slightly greater deposition of cellulose in the fibre.

(3) *Maturity count.*—The results of the maturity test show that the irrigated samples contain, on the whole, a somewhat higher percentage of mature fibres than the unirrigated samples. The mode of sowing, on the other hand, has not affected the maturity count of this cotton in any way, as identical values are obtained for three unirrigated samples sown in different ways. These results are in line with those obtained for hair weight per inch, and show that the effect of plentiful supply of water is to increase the percentage of mature hairs in this cotton.

(4) *Waste losses.*—The results for the total loss suffered by the samples up to the spinning point are interesting as they show that in 17 out of 18 cases the irrigated samples gave lower waste losses as compared with the unirrigated samples, in the remaining case the losses for the two types of samples were equal, while in no case did the total loss of the irrigated sample exceed that of the unirrigated sample. The differences between the waste losses of the two types of samples are small in 1932-33, but in the following season they lie between 2 per cent and 6 per cent, the lowest loss in each of the three sets of samples corresponding to 9 in. spacing, 4 in. spacing and broadcast seed, being given by the sample which was irrigated once in three weeks. The mode of sowing, on the other hand, had practically no effect on the total loss. We may, therefore, conclude that while the total loss sustained by this cotton in the blow room and the card room is independent of the mode of sowing, it is somewhat less if the cotton is grown under irrigation.

(5) *Spinning performance.*—In 11 out of 18 cases the spinning performance of the irrigated samples is slightly lower than that of the unirrigated samples, in five cases it is equal, while only in two cases it is slightly better. Thus, on the whole, the yarns spun from the irrigated samples gave lower strength as

compared with those spun from the unirrigated samples. The differences, however, in the performance of the two types of samples are quite small and are most probably due to the effect of irrigation on the hair weight per inch of this cotton. Other factors being the same, a coarse cotton would give a lower performance primarily because of the fewer fibres present in a cross-section of the yarn of the same count as spun from a relatively finer cotton. It should finally be stated that the spinning performance was found to be unaffected by the mode of sowing of the samples employed in this experiment.

(6) *Neps per yard.*—The yarns spun from the unirrigated samples were somewhat neppy in 1932-33 and neppy in the following seasons. In both seasons, growing the samples under irrigation reduced the neppiness of the yarns, in some cases by more than 50 per cent. The mode of sowing, on the other hand, had practically no effect on the degree of neppiness of the yarns. We may, therefore, conclude that while the yarn-neppiness of this cotton is independent of the mode of sowing adopted in this experiment, it is appreciably reduced by growing the cotton under irrigation. This observation agrees very well indeed with the results of an investigation carried out at the Technological Laboratory and described in Technological Bulletin Series B, No. 20 which showed that the degree of neppiness of a cotton was significantly correlated to the percentage of mature hairs present in it. In the present case irrigation increased the proportion of mature hairs and hence improved the appearance of the yarn as regards its neppiness.

Fibre-test results, 1934-35

The results of mean fibre-length, fibre-weight per inch and maturity count determination for the different systems of irrigation and different spacings are summarized in Tables IX to XI. The following conclusions are drawn from a consideration of these results.

(1) *Fibre-length.*—On the whole, the system of irrigation had very little effect on the mean staple length. This agrees with the results of the previous two seasons. The effect of spacing was a little more marked, the 4 in. spacing giving, on the whole, better results than the 9 in. spacing, which in its turn gave better results than broadcast sowing.

(2) *Fibre-weight.*—The irrigated samples gave somewhat higher values than the unirrigated samples. This agrees with the results of the previous seasons, where it was found that the effect of plentiful supply of water by irrigation was to deposit more cellulose in the fibre. The differences between the various irrigated samples are non-significant. The samples grown with 4 in. spacing are, on the whole, somewhat finer than those grown either with 9 in. spacing or from broadcast sowing.

(3) *Fibre-maturity.*—The samples which were irrigated once a week had, on the whole, a higher percentage of mature hairs than the others. This again agrees with the observation for the earlier seasons which recorded a higher percentage of mature hairs for the irrigated samples. As regards spacings, however, there is practically no difference between the 9 in. spacing and the broadcast sown samples, but the samples grown with 4 in. spacing had, on the whole, a lower percentage of mature fibres.

Summary

A complex experiment consisting of two methods of irrigation, three irrigation frequencies and two spacings, was conducted on Cambodia cotton for

TABLE IX

Fibre-length (inches)

Spacings	Intervals of irrigation			
	1 week	2 weeks	3 weeks	Dry
4 in.	0·89	0·90	0·93	0·94
9 in.	0·91	0·90	0·88	0·88
Broadcast	0·88	0·90	0·88	0·88

TABLE X

Fibre-weight per inch (millionth of an ounce)

Spacings	Intervals of irrigation			
	1 week	2 weeks	3 weeks	Dry
4 in.	0·133	0·136	0·133	0·128
9 in.	0·138	0·136	0·153	0·136
Broadcast	0·146	0·147	0·127	0·132

TABLE XI

Maturity (per cent)

Spacings	Intervals of irrigation							
	1 week		2 weeks		3 weeks		Dry	
	Mature	Im-mature	Mature	Im-mature	Mature	Im-mature	Mature	Im-mature
4 in.	48	29	40	33	41	32	44	27
9 in.	45	34	46	24	49	28	46	33
Broadcast	54	27	45	33	39	40	50	30

three seasons at Cotton Breeding Station, Coimbatore. The lint produced in each treatment was examined for fibre properties and spinning performance at the Technological Laboratory, Bombay. The results pointed out that :—

(*a*) Irrigating Cambodia after December improved the yield definitely.

(*b*) Irrigating once a week tended to give highest yields ; but the increase obtained was not of such a magnitude as to pay for the extra expense involved in giving additional irrigations.

(*c*) Irrigating once in three weeks was most profitable.

(*d*) The quantity of water consumed at each irrigation by 'one week' plots was distinctly less than in plots irrigated once in three weeks.

(*e*) On a level field there was little difference in the consumption of water between ridge and bed system of irrigation.

(*f*) Variations in the density of plant population had no effect on water consumption.

(*g*) Neither the frequency of irrigation nor the different modes of sowing—each within the limits of this experiment—had any appreciable effect in 1932-33 and 1933-34 on the mean fibre-length of this cotton. In 1934-35 season, however, the 4 in. spacing gave, on the whole, somewhat higher mean length than 9 in. spacing, which, in its turn, gave slightly better results than broadcast sowing.

(*h*) While the hair-weight per inch of this cotton is practically independent, in 1932-33 and 1933-34 seasons, of the mode of sowing employed in these tests, it shows a tendency to increase with the amount of irrigation given to the crop. In other words, with a more plentiful supply of water, there is a greater deposition of cellulose per unit length in the fibre. In 1934-35 season the samples grown with 4 in. spacing are proved, on the whole, to be somewhat finer than those grown either with 9 in. spacing or from broadcast seed.

(*i*) Irrigated samples contain, on the whole, a higher percentage of mature fibres as compared with the unirrigated samples. The mode of sowing, on the other hand, did not affect the maturity count of this cotton in any way in 1932-33 and 1933-34 seasons. In 1934-35, however, the samples grown with 4 in. spacing contained a lower percentage of mature hairs.

(*j*) While the total loss sustained by this cotton in the blow room and the card room was independent of the mode of sowing, it was somewhat less when the cotton was grown under irrigation.

(*k*) While the yarn neppiness of this cotton is independent of the mode of sowing adopted in this experiment, it is appreciably reduced by growing it under irrigation. This agrees very well with an earlier conclusion of the laboratory that the degree of neppiness of a cotton is significantly correlated to the percentage of mature hairs present in it.

(*l*) The spinning performance was found to be unaffected by the mode of sowing of the samples employed in this experiment. The yarns spun from the irrigated samples, on the whole, gave lower strength as compared with those spun from the unirrigated samples. The difference, though small, is most probably due to the effect of irrigation on the hair-weight of this cotton.

ACKNOWLEDGEMENT

The authors take this opportunity to thank Dr S. Kasinatha Ayyar and Mr K. L. Ramakrishna Rao for help rendered during work on these experiments.

APPENDIX

Spinning master's reports

	4 inch spacing				9 inch spacing				Broadcast			
	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks	Dry	1 week	2 weeks	3 weeks
1932-33												
Colour						Creamy-white ; brightish						
Cleanliness							Clean					
Feel	...	Soft ; smooth	Good ; smooth	Good	...	Soft ; smooth	Smooth and bodied	Good	Good ; smooth	Smooth and bodied	Smooth and bodied	Good ; smooth
Ginning and neppiness	...	Well-ginned	Well-ginned.	Well-ginned	...	Well-ginned	Well-ginned	Well-ginned	Well-ginned	Well-ginned	Well-ginned	Well-ginned
Card sliver							Clean					
Card-web	...	Good	Even and nep-free	Even and nep-free	...	Good	Even and nep-free	Even and nep-free.	Even and nep-free	Even and nep-free	Even and nep-free	Even and nep-free
1933-34												
Colour						Creamy-white ; brightish						
Cleanliness	Clean	Very clean.	Clean	Clean	Clean	Very clean	Clean		...	...	...	...
Feel	Soft ; smooth	Good-bodied	Good	Good	Soft ; smooth.	Good ; bodied	Good	Good	Soft ; smooth	Good	Good	Good
Ginning and neppiness	A little knotted	Well-ginned	Fairly well-ginned	Fairly well-ginned	A little knotted	Well-ginned	Fairly well-ginned.	Fairly well-ginned	A little knotted	Well-ginned.	Fairly well-ginned	Fairly well-ginned
Card-sliver							Clean					
Card-web	A little cloudy ; somewhat neppy	Cloudy ; slightly neppy	Even ; somewhat neppy	Even ; somewhat neppy	A little cloudy ; somewhat neeppy	Cloudy ; slightly neppy	Even and somewhat neppy	Even and somewhat neppy	A little cloudy ; somewhat neppy	Good	Even and somewhat neppy	Even and somewhat neppy

INDIGENOUS AND EXOTIC COTTONS OF IRAN

BY

M. A. A. ANSARI

Institute of Plant Industry, Indore, Central India

(Received for publication on 6 April 1939)

(With two text-figures)

INTRODUCTION

IN connection with the improvement of *herbaceum* cotton in India by breeding it was considered that it would be worth collecting early and long stapled types of *herbaceums* from Iran. A scheme to undertake a survey of the Iran cotton was therefore suggested to the Indian Central Cotton Committee in 1935 and, when it was sanctioned in 1936, I was deputed for the work. I left Indore on August 31, 1936 and entered the Iranian territory at Zahidan on September 9, 1936. The actual survey took a period of eight weeks. The only information available about the cottons in Iran was a record by the Russian worker, Cheranykaroskya [1930], who had described the great variability of *herbaceum* cottons in Siestan and Khorasan.

COTTON AREAS VISITED AND THEIR CHARACTERISTICS

The whole journey in Iran, of about 4,000,miles was done in a car, excepting a few impassable places in Siestan and Khorasan where it was performed on horseback. In all 56 different localities were visited and 1,500 single plant samples of *kapas* and 165 samples of soil were collected. The cotton areas visited have been divided into three regions, eastern, western and northern and their description is given below :—

The eastern region includes Zabol (Siestan) and the area from Zahidan to Meshhad district. It is for the most part a plain sloping from an elevation of 4,000 ft. in the west to 1,500 ft. above sea level in the east. The fertile areas under cottons are interspersed with large salt areas. The soil in the cultivated areas is for the most part light sandy loam of the loess kind and, excepting Zabol, is predominantly under *herbaceum* cottons. The cultivated parts have coarse sand with small fragments of rocks on the surface. The colour of the soil varies from grey to brown. Rainfall in the western part of this region averages about 9 in. while in the eastern 4 in. only. The range of temperature at Meshhad is from 15° F. to 76° F., the average being 56·3.

The northern region consists of a strip of very fertile land, beginning from Sabzavar and extending as far as Nowshehr in Mazandaran on the Caspian. The soil from Neishapoor to Sudkhar is heavy sandy loam and is predominantly under *hirsutum* cottons. The region from Davarzan to Semnan has for most of the parts light loam of the loess kind and is also under *herbaceums*. The uncultivated regions are sandy. In the Mazandaran area bordering on the Caspian Sea, the soil is again heavy sandy loam, the cotton growing there being exclusively of *hirsutum* type. The colour of the soil varies from grey

to brown excepting in Mazandaran area where it is black or dark brown. Mazandaran has an yearly rainfall of 50 in. to 80 in. The range of temperature at Tehran is from 30 to 111° F. and the average 60·4. The rainfall in Tehran varies from about 9 in. to 10 in.

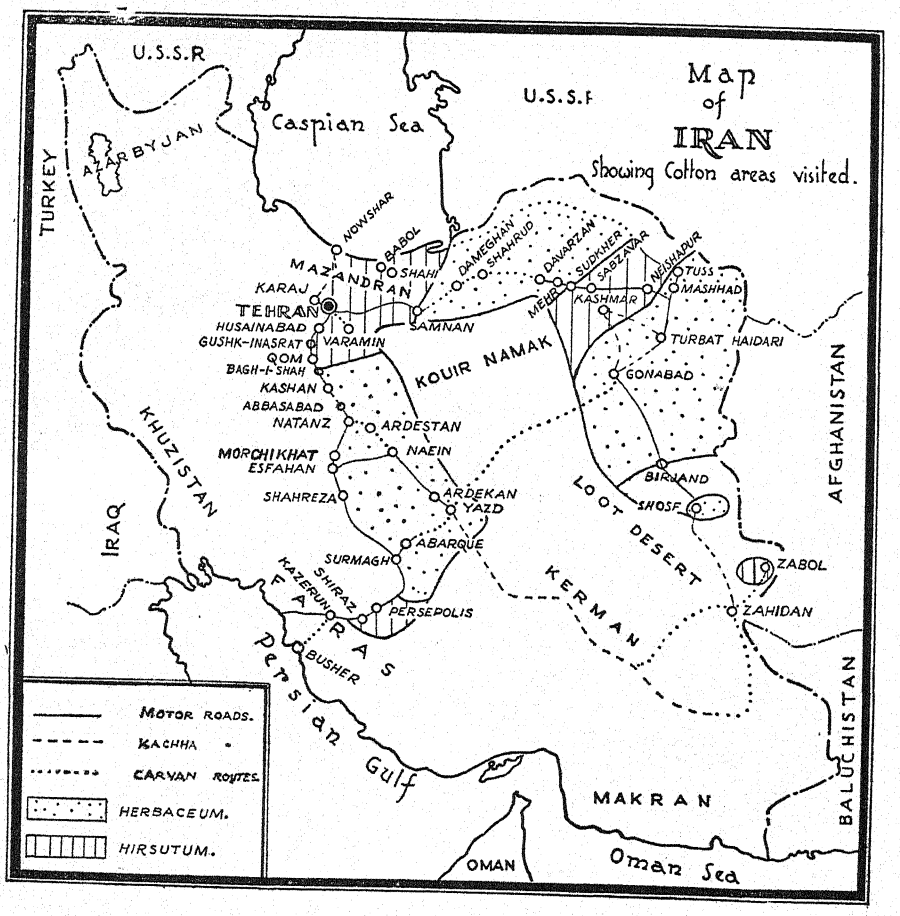


FIG. 1. Map of Iran showing cotton areas visited

The western section comprises the whole of the area from Tehran to Shiraz. The cultivated areas are far apart. Districts of Tehran, Qom, Kashan, Isfahan, Yazd and Shiraz are very fertile and have vast areas under cotton. The intervening regions are barren and sandy. The way from Shiraz to Bushire is extremely hilly.

The soil of the cultivated areas from Tehran to Morchikhat is heavy sandy loam. From Anoushirwan to Yazd the soil is light loam, with the exception of Isfahan which has heavy sandy loam. The cotton growing in the western region is mostly the *herbaceum* type including the heavy soil areas like those of Isfahan and those between Tehran and Morchikhat. The soil of the uncultivated areas from Anoushirwan to Shiraz is highly saline. The colour of the soil for most of the parts varies from grey to brown, it being dark brown in

Shiraz. The average temperature and rainfall for Isfahan, Shiraz and Bushire are given below :—

——	Maximum °F.	Minimum °F.	Average	Rainfall (in.)
Isfahan	106	—3	58·0	5·4
Shiraz	113	21	65·0	?
Bushire	109	75	91·0	13·4

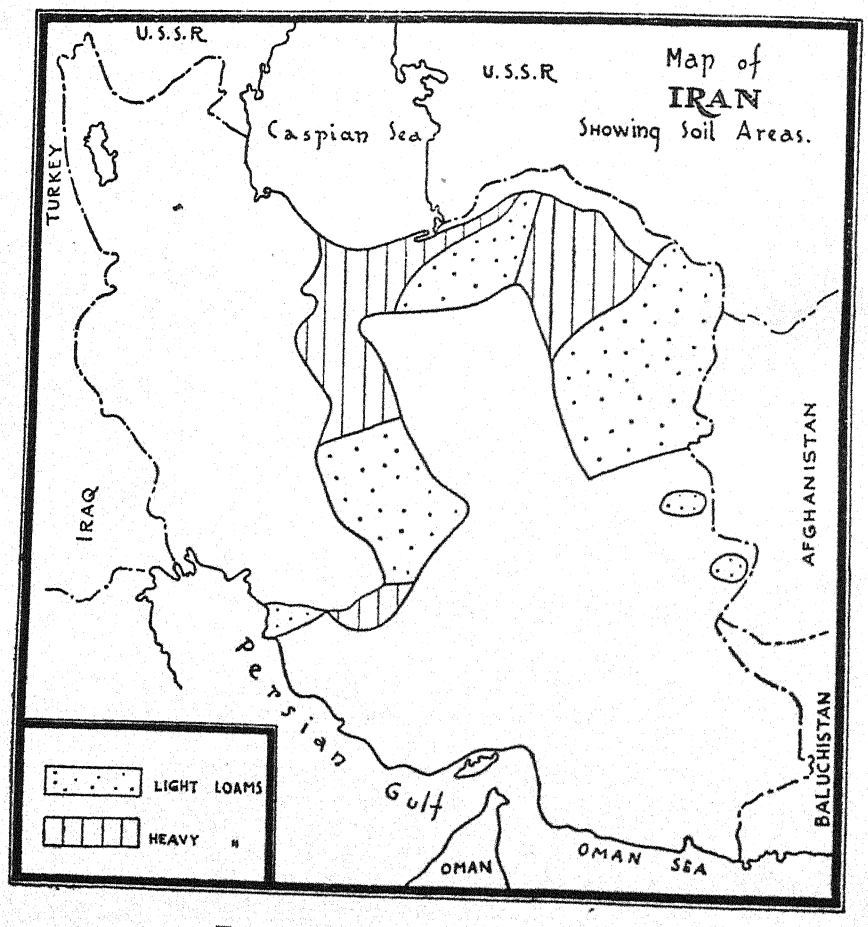


FIG. 2. Map of Iran showing soil areas

AGRICULTURAL DETAILS OF COTTON GROWING

The sowing time for cotton all over Iran extends from March to May except in South Iran where it is earlier, viz. the first three weeks of February. The seed is usually broadcast though sowing in lines with bullock-drawn drills is coming into vogue. A seed rate of 30 to 40 lb. per acre is used in the case of a broadcast crop, while about 15 lb. suffices for line sowing. Except in

Mazandaran area which receives a rainfall of 50-80 inches during the cotton season, cotton all over Iran is irrigated. The number of irrigations varies from four to six depending on the availability of water.

The crop starts flowering from the beginning of May and goes on until the end of July, roughly about 80 days after sowing. The picking of cotton is carried out from July to October, the first picking commencing about 60-65 days after the beginning of the flowering phase. In order to hasten maturity it is a general practice in Iran to strip the plants of its leaves and also to top them at any stage between bud and boll formation. The yield of seed cotton is said to average between 400 and 600 lb. per acre although the cotton statistics for 1932-33 records it as over 700 lb. for that year.

The Entomological Department at Tehran has indentified the undermentioned pests and recorded their comparative incidence.

Pests which cause very heavy damage :—

a. *Heliothis obsoleta* (Bollworm) 30 per cent damage in Mazandaran.
b. *Aphis gossypii* and *Aphis laburni* (plant lice) 20 per cent damage in Khorasan and Mazandaran.
c. *Oxycaraenus hyalinipennis* (cotton bug)
d. *Dysdercus delauneyi* (stainer) causes damage in the province of Faras.
e. *Nezara viridula* (shield bug) causes damage along the Persian Gulf.
f. *Cicadetra Ochreata* causes damage in North Iran.
g. *Acyrothosyphon gossypii* causes damage in North Iran.

Pests which cause moderately heavy damage :—

h. *Gryllus desertus* (cricket)—North Iran.
i. *Gryllotalpa gryllotalpa* (mole cricket) —North Iran.
j. *Lethrus*—Mazandaran.
k. *Epicanta erythrocephala* (Beetle)—Tehran.
l. *Heliothis peltigera* (Bollworm)—North Iran.
m. *Plusia gamma* (leaf eater)—Tehran and Shahrud.
n. *Botinoderes punctiventris*—Tehran.
o. *Monastria inermis*—Tehran.
p. *Oedalaeus decorus*—North Iran.
q. *Anacridium aegyptium*—South Iran.
r. *Elateridae* (wire worms)—two species—Varamin.

It would be seen that most of the above pests and diseases are common in North Iran which is predominantly the American cotton area. The American cottons suffered heavily from pests and diseases, while the indigenous ones were comparatively free.

Cotton industry in Iran

Cotton cultivation in Iran has recently been organized, having become a State monopoly. The company controlling the cotton cultivation is known as ' Shirkat-i-Sahami Pamba ' consisting of shareholders from amongst the Iranees. It is financed by the Agricultural Bank of Iran which is a branch of the National Bank of Iran established in 1930 and has an authorized capital of 50,000,000 *rials* or £625,000 approximately. Both the Company and the Bank have branches all over the country. The Company sells seeds to

cultivators at a nominal rate. The cultivators should sell the produce to the Company only and the latter have an exclusive right to export it or sell it in the country. As cotton picking ends by October, the ginning factories work from November till the end of March, the export time being from December to May. According to cotton statistics of 1932-33 the total area under cotton and the total yield are about 1·5 million acres and 2·9 million bales respectively (details given in Appendix I).

There was a project to increase the area to twice its size. A circular was issued by the Shah of Iran, forbidding the cultivation of opium poppy and to grow cotton in its place. In 1934, the Province of Khorasan (the largest cotton-growing province in Iran) produced 60,000 bales of 250 lb. each of cotton (47,000 bales of the indigenous cotton, 10,000 bales of 'Pure American cotton' and 3,000 of 'Felistani'). The market rates given below were those offered by Russian buyers. They bought delivered on the frontier near Ashkabad at 42/- *rials* a pood nett (Rs. 6/9 for 36 lb.) for local cotton, at 62/- *rials*, (Rs. 9/11) for American and at 72/- *rials* (Rs. 11/4) for Felistani cottons (1 pood=36 lb. approximately, 1 *rial*=1/6·4 rupee). The packing charges were about 10/- *rials* (Re. 1/9) a bale.

Indigenous cottons

The indigenous cottons of Iran known locally as *Mahali, Rasmi* or *Bumi*, belong to *G. herbaceum* var. *typicum* [Hutchinson and Ghose, 1937]. The various forms as found during the survey can be grouped as follows :—

(*a*) Plants 1 ft.-5 ft. and vigorous, leaves green to deep green, bolls big and rounded with small beak, bolls opening slightly when ripe [*c. f.* Grade 4, Hutchinson and Ramiah, 1938], lint white, soft, fine and long, predominantly late. Only earlier plants ready for picking at the time of the visit.

(*b*) Intermediate between (*a*) and (*c*)

(*c*) Plants 1-2½ ft., weak, leaves green to pale green, bolls small and not so rounded as in (*a*), with prominent beak and opening widely when ripe [c. f. Grade 2, Hutchinson and Ramiah, 1938]. Lint white, dull white, *khaki* or deep *khaki*, coarse and short. Predominantly early, almost all plants ready for picking at the time of the visit. Considerable variation was found in the colour of the leaves and therefore it should not be regarded of any taxonomic importance.

Distribution of the above three types

	Locality	Type
Eastern region	Shosf Birjand to Gonabad	Intermediate type (*b*) predominant. All the three types almost equally distributed.
Northern & western region	Turbat-i-Haidri to Morchikhat.	Open bolled type (*c*) predominant.
Western region	Anoushirwan to Persepolis.	Intermediate type (*b*) predominant. The cotton of these parts was soft to feel and it was just possible that it might have come from Gonabad *via* Tabbas and Posht-Badam. There was a good deal of traffic on that line (Fig. 1.)

The variation in all plant characters, particularly in hairiness, number, size, shape and opening of the boll, lint characters and ginning percentage was very great in areas ranging from Shosf to Tuss in the east, Ghademgala and Sudkhar to Dameghan in the North and Qom to Bagh-i-Shah in the north-west.

At Dameghan there were types which had all the characters of var. *typicum* but the bolls were ½ in. in size. Their lint characters varied a good deal from long and soft at Dameghan to either short and soft or short and coarse at Meshhad, Tuss and the remaining of the above places.

Another interesting feature was the occurrence of types intermediate between vars. *typicum* and *frutescens*. [Hutchinson and Ghose, 1937]. They were found in considerable numbers in Meshhad and Tuss, but stray plants could be found all over from Zabol (Siestan) in the east to Bagh-Shah in the north-west.

Forms belonging to *G. herbaceum* var. *typicum* and with red pigment all over the plant body (stem, leaves, flowers, bolls) were also observed. There was considerable variation in the distribution of pigment over the leaves. Some times only the leaf lobes or a part of the leaf would be found red and the rest green. They are locally known as *parsiah* or black winged, on account of the deep purple colour which their bracteoles acquire when the boll is mature. Their lint is white and of average quality. They were found in varying proportions from Meshhad to Isfahan as shown below :—

Meshhad to Tehran	Stray plants
Gushk Nasrat to Kashan	2 to 10 per cent
Abbasabad to Isfahan	1 to 10 per cent

Forms belonging to *G. herbaceum* var. *typicum* and having *khaki* lint were found. They also are known as *Mahali* cottons. The only other name given to them is *surkhcha*, i.e.(resembling red). They formed 10 to 20 per cent of the component of cotton crop in Birjand area and 2 to 5 per cent in Kashan and Morchikhat areas. *Khaki* cottons are late to mature as compared to white linted ones. Their lint which is either short and coarse or of average quality is used for making coarse hand-spun cloths or *khaki* curtains. The latter are very popular amongst Iranees. It is said that formerly the *khaki* cottons were cultivated on a larger scale. The demand being now for long-stapled cottons, the cultivation of *khaki* cotton is decreasing every year.

Examination of the material

Single plant selections.—859 plants (778 white and 81 *khaki*) were selected from different localities in Iran, based on earliness, boll size and length and softness of the lint. These were examined for staple length, swollen-hair diameter and ginning percentage. The procedure adopted was as follows :—

Halo length of all 859 plants was measured by Bailey's protractor. (maximum halo length on five seeds per plant).

Plants which had halo lengths of 28 mm. and above were examined for swollen-hair diameter (fineness). Such plants numbered 499 (493 white and 6 *khaki*).

Out of the plants examined for fineness, the following were selected and ginned :—

(*a*) Those which had 0·023 mm. and below swollen-hair diameter.

(*b*) Those which had 33 mm. and above lint length irrespective of their swollen-hair diameter. Such plants numbered 240 (234 white and 6 *khaki*).

TABLE I

Area	Halo length in mm.				Swollen hair diameter (in units of 0·0033 mm.)				Ginning percentage			
	No. of plants examined	Range of halo length	Mean	σ	No. of plants examined	Range of S.H.D. examined	Mean	σ	No. of plants examined	Range of ginning percentage	Mean	σ
Eastern .	White 515 Khaki 55	25-36 20-30	30·3 23·8	1·90 2·49	White 418 Khaki 6	4–10 7	7·4 7·0	0·99 ...	White 222 Khaki 6	19-59 34-39	32·9 ...	5·61 ...
Northern.	White 151	21-31	25·9	1·90	White 24	7–10	8·5	0·66	White 1	40	40·0	...
Western .	White 112 Khaki 26	20-35 15-25	26·1 20·7	2·53 2·58	White 51	7–8	7·6	0·47	White 11	32-43	37·0	3·14

REMARKS.—It will be seen from the table that eastern region has given the best material as far as the fineness of the lint is concerned. In halo-length though the variation is not as great as that in the western region, the mean value is the highest. The western region comes next in the aggregate qualities of the material. The *khaki* cottons from all regions were much inferior to the whites.

In addition to single plant selections, there were 29 bulk samples, nine of which were obtained through His Britannic Majesty's Consuls at Tehran and Meshhad and the remaining 20 through the Agricultural Department, from Isfahan area. They were examined for lint length, feel and ginning percentage. Data for samples received through His Britannic Majesty's Consuls are summarized below :—

Locality	Boll characters	Halo-length mm.	Feel	Ginning percentage
G. herbaceums				
1. Marvasti . .	Partly open	28-30	Soft	33·3
2. Maibad . .	,, ,,	25-29	Soft	36·3
3. Herat . .	,, ,,	25-29	Soft	35·2
4. Ardekan (mostly R plants)	Open	25-27	Coarse	45·4
5. Balk locality .	Open	22-26	Coarse	37·5
6. Unknown Khaki .	Open	20-25	Coarse	40·0
7. Birjand (soft cotton)	Closed and partly open bolls	25-32	Soft	25·0
8. Birjand (coarse cotton)	Open	24-29	Coarse	37·5
9. Meshhad . .	Partly open	25-30	Moderately soft	40·0

The samples obtained through the Agricultural Department, Isfahan, were all short and coarse and were therefore rejected.

The selected material of *herbaceum* cottons has been distributed between Viramgam, Coimbatore and Trinidad.

A comparison of the Iran *herbaceums* with the standard Indian *herbaceums* with regard to season, soil, yield quality etc. can be had from the tabular statement (Appendix II).

Exotic cottons

Egyptian cotton (G. *barbadense*) is extensively cultivated along the coast of Persian Gulf. In the rest of Iran efforts are being made to replace indigenous cottons by types of American cottons and at the time of visit American cottons formed an important component of cotton crop all over Iran. Western Iran was said to be practically all under types of American cottons, while on the route travelled Neishapur and Sabzawar in the north-east, Mazandaran, Tehran and Qom in north and Shiraz in the south were important centres of American cotton cultivation (Fig. 1.) Besides the cotton known in Iran as pure American, Felistani, Prerout, Iraqi and Novortski were cultivated. Felistani, is however, the most prized cotton in Iran. Though late, it is long stapled and soft. It is said to have been introduced about twelve years ago by a certain Mr. Hakeemi who brought seed from Russia and grew it in Felistan (North Iran). According to Dr. Burns [1938] it is a cross between Egyptian and American cottons made by Mr. Hakeemi. Since it did very well there, the Agricultural Department encouraged its cultivation all over Iran.

Types of American cotton

Felistani cotton, as grown on the experimental farm at Karaj (Tehran) differed from a typical *G. hirsutum* in the following characters :—

Leaf deeply constricted at the base, leaf lobes narrowly triangular, bracteoles not closely investing the bud, flower or boll, corolla moderately expanding, bolls tapering and pointed.

In fields, however, there was a great variation in morphological characters, and in Felistan plants were found in considerable numbers which conformed in every detail to *G. hirsutum*. Felistani can be classified into two classes according to size of seed, and three according to colour as shown below :—

1. Small-seeded . . . . a. black seed, no fuzz, tuft at the pointed end, lint short.
2. Big-seeded . . . . b. brown seed, fuzzy, lint long.
   c. green seed, fuzzy lint long.

Prerout is extensively cultivated in Mazandaran area. Plants are sympodial, tall and vigorous up to 8 ft. in height. Morphological characters resemble those of *G. hirsutum*. The Agricultural Officer, Shahi (Mazandaran), said it was a cross between two varieties of *G. hirsutum*. Prerout is an early and high yielding type with moderate lint chararters.

Iraqi and Novortski are being tried at all the experimental stations in Iran. *Iraqi* is medium in time of maturity, sympodial in habit 1 ft. to 6 ft. high, and thick stemmed. It is a typical *G. hirsutum*, and in lint characters is almost as good as Felistani. Novortski is morphologically similar to Iraqi but is short stapled and soft.

The *hirsutums* on the whole showed much less variation in morphological characters than the *herbaceums*, which may be accounted for by the fact that they have been introduced in the course of the last 12 years.

Examination of the material

Single plant selections.—In making field collections it was not possible to identify the variety with any certainty and in the examination of the material, therefore, no account was taken of the name under which the cotton was being grown. 302 of the plants collected on the basis of earliness, boll size, length and feel of lint, were examind for lint length, fineness and ginning percentage in the same way as described for *G. herbaceum*.

TABLE II

Area	Halo length in mm.				Swollen hair diameter (in units of 0·0033 mm.)				Ginning percentage			
	No. of plants examined	Range of halo-length	Mean	σ	No. of plants examined	Range of halo-length	Mean	σ	No. of plants examined	Range of ginning percentage	Mean	σ
Eastern .	131	24–37	29·5	2·99	93	6–9	7·3	0·62	41	30–47	36·0	3·87
Northern .	100	23–36	29·5	3·15	70	7–10	7·8	0·62	19	27–43	33·0	4·31
Western .	71	26–36	29·7	2·24	61	6–8	7·2	0·52	60	15–48	35·9	5·22

REMARKS.—It will be seen from the table that taking into consideration all the three characters, lint length, fineness and ginning percentage, the western region has given the best material and the eastern the second best.

Bulk samples.—These samples where obtained from His Britannic Majesty's Consul at Meshhad and their characters are summarized below :—

Locality	Boll size	Lint length mm.	Feel	Ginning percentage
Meshhad (*G. hirsutum*) .	Moderate	25–30	Soft	36
Meshhad (Felistani) . .	Large	26–31	Soft	23

The selected material of *hirsutums* has been distributed between Coimbatore, Lyallpur and Trinidad.

The lint of both the *herbaceums* and *hirsutums* collected in Iran were sent for fibre test to the Technological Laboratory, Matunga. The fibre particulars received from there are given below :—

	G. hirsutum	*G. herbaceum*
1. Mean fibre length (inch)		
(a) By Balls sorter	1·04	0·90
(b) By Baer sorter	1·08	0·90
2. Mean fibre wt. per inch (one millionth of an ounce) . . .	0·136	0·120

The *hirsutums* according to the report are 18 per cent longer but 13 per cent coarser than the *herbaceums*. The former is rather coarse for its length and has a rough feel while the latter is finer than is usually the case with Indian *herbaceums* and has a slightly silky feel.

SUMMARY

(1) The indigenous cottons, i.e. the *herbaceums*, exhibited great variability in ginning percentage, lint length and fineness. The introduced cottons, i.e. the *hirsutums* were variable in the first two characters only. Variation in morphological characters of the *herbaceums* was considerably greater than that of the *hirsutums*.

(2) The best material of *herbaceums* was obtained from the eastern region good material was also found in western Iran, but that collected in the north

was inferior. Zabol (Siestan area) in the east was also reputed to produce good quality and highly variable material but, due to failure of the crop in 1936 season, enough samples could not be collected to give any detailed information about it.

(3) According to the report received from the Technological Laboratory, Matunga, on the material brought from Iran, the *hirsutums* were 18 per cent longer but 13 per cent coarser than the *herbaceums*. The former was rather coarser for its length and had a rough feel, while the latter was finer than was usually the case with Indian *herbaceums* and had a slightly silky feel.

(4) The *hirsutums* in Iran suffered heavily from pests and diseases, while the *herbaceums* were found to be comparatively free.

(5) The *herbaceums* that were come across were all highly sympodial as would be expected in a country with early frosts and severe winters. To hasten maturity, it is a general practice in Iran to pluck the leaves and top the plants at all stages from the bud to the boll-forming period.

(6) The cotton samples collected have since been grown at Viramgam (Gujrat) and Coimbatore. A part of the material is also being tried by Mr. J. B. Hutchinson at Trinidad.

(7) The analysis of the soil samples showed that excepting the region between Qom and Isfahan, which had heavy soils and was predominantly a *herbaceum* area, the light soils had predominance of the *herbaceum* type and the heavy soils that of the *hirsutums*. Zabol (Siestan) had light sandy loam and though at the time of visit was predominantly under *hisrutums* it was essentially a *herbaceum* area and has been well known for the good qualities of the latter.

(8) The total area under cottons in Iran in 1932-33 was about 1·5 million acres and the produce about 2·9 million bales of 400 lb. each, thus giving an yield of about 700 lb. of *kapas* per acre.

ACKNOWLEDGEMENTS

I am grateful to the Indian Central Cotton Committee, Bombay, and the Director, Institute of Plant Industry, Indore, for deputing me to survey the cotton areas in Iran, and I feel highly indebted to Sir Bryce Burt for very kindly affording me every facility for arranging my tour in that country.

I am highly indebted to Mr T. R. Low and Mr J. B. Hutchinson for their helpful advice and the keen interest they took in the progress of my work in Iran. To Mr Hutchinson's valuable guidance and criticisms in examining the material, I owe the report submitted to the Cotton Committee in February 1937. My thanks are due to Mr K. Ramiah for his help in rewriting the original report in the form of a paper. I am also thankful to Mr O. K. Caroe, then Deputy Secretary, Foreign and Political Department, Government of, India, Mr N. M. Butler, Counsellor, British Legation, Tehran, Major J. Campbell British Vice-Consul, Zahidan and Aqai Adal, Naib Raees-i-Falahat, Tehran, for affording me the facilities required during my tour in Iran.

REFERENCES

Ahmad, N. (1938). *Ind. Cent. Cott. Comm. Tech. Lab. Bull. Series A, No.* **45**
Burns, W. (1938). *Agric. Live-Stock in Ind.* **8**, 427
Chernyakouskaya, E. G. (1930). *Bull. Appl. Bot. Genet. and Plant Breeding* **23**, 3
Hutchinson, J. B. and Ghose, R. L. M. (1937). *Ind. J. Agric. Sci.* **7**, 233
Hutchinson, J. B. and Ramiah, K. and the members of two special sub-committees (1938). *Ind. J. Agric. Sci.* **8**, 567

APPENDIX I

Details of area under cultivation and yield of cotton in Iran

Name	Acres	Yield of *kapas* in bales of 400 lb. each
Tehran	25293	45641
Azarbyjan (east)	15931	32478
Azarbyjan (west)	2487	5779
Khorasan	26962	51668
Kerman	5063	4795
Siestan	1235	1632
Faras	820	2583
Khouzistan	291	5959
Khamseh	1111	1959
Qazvin	2766	6474
Hamadan	420	1273
Kirmanshah	252	354
Kurdistan	*	*
Louristan	*	*
Iraq	840	1861
Golpayegan	*	*
Malayer	494	490
Isfahan	11599	18512
Yezd	6879	20705
Kashan	6661	14578
Qom	1265	2922
Semnan	8497	11101
Shahroud	210	637
Dasht-i-Gorgan	743	1485
Gorgan	7632	10105
Mazandaran	22477	44730
Guilan	*	*
Ports of Persian Gulf	25	653
Total	149956	288374

*The statistics for Kurdistan, Louristan, Golpayegan and Guilan were not available.

APPENDIX II

Comparison of the Iran herbaceums *with standered Indian* herbaceums

Datta for Indian cottons are from *I. C. C. C. Tech. Bull. No. 45, 1938*

Iranian herbaceums

Type	Districts of growth	Growing period	Soil	Annual rainfall	Temperature in °F.	Yield of *Kapas* per acre	Ginning percentage	Fibre length in inches Balls Baer	Fibre wt. per inch in millionth of an ounce
Iranian *herbaceums*	Siestan, Khorasan, Guilan and areas of Qom, Kashan Isfahan and Faras.	Sown all over Iran from March to May except in South Iran where it is earlier, the first 3 weeks of February. Picking from July to October.	Predominate in light loam. The exceptions are the heavy soil areas of Tehran to Morchikhat and of Isfahan.	In Siestan and east Khorasan about 4". In western Khorasan about 9". In Tehran and round about 5 in. In Isfahan about 6 in. and in Bushire—about 13 in. The number of irrigations varies from 4 to 6 depending upon the availability of water.	At Mashhad (Khorasan) mean=56·3 and range from 15 to 76. At Tehran, mean =60·4 and range from 30 to 111. At Isfahan mean =58·0 and range ==—3 to 106. At Shiraz, mean=65·0 and range =21 to 113. At Bushire average =91·0 and range =75 to 109.	400 to 600 lb.	33 per cent in East Iran 40 per cent in Guilan area and 37 per cent in Isfahan area.	0·90, 0·94	0·195
Indian herbaceums									
Jaywant .	Dharwar, Belgaum Bijapur, etc.	Sown from the 1st week of August to the end of September and usually picked from the 2nd week of February up to middle of April.	Deep and medium black soil.	20 in. to 30 in. .	Average minimum about 60.	Normally about 300 lb.	26–29	0·96, 0·94 in 1937-38.	0·195 in 1937-38.
Surat 1027 ALF.	Broach tract	Sown from third week of June and picked from mid March onwards.	Black cotton soil	30 in. to 40 in. .	Mean 85 from April to August Mean 81 from September to November.	424 lb. in 1937-38.	33·3	0·99, 0·97	0·155
Wagad 8 .	North Gujrat, N. W. Kathiawar and Cutch.	Sown in the beginning of July and picked in March.	*Besar* a saltish alluvium	13 in. to 30 in. .	Mean 110 Minimum 52. Lowest monthly average =58·7 (January).	Average from 1923-38 594·7 lb.	42	0·82, 0·82 in 1937-38.	0·211 in 1937-38.
Hagari .	Parts of Bellary.	Sown from the last week in August to the end of September and picked from about the first week of February to the end of March.	Black cotton soil	Normally 20 in. .	Mean minimum =65·1 Range 77·8 to 42·2. Mean maximum =91·4 Range 104·7 to 80·7	Normally 270 lb.	30	0·88, 0·87 in 1937-38.	0·180

MEGASPOROGENESIS AND THE ORIGIN OF TRIPLOIDS IN *SACCHARUM**

BY

S. NARAYANASWAMI, M.Sc.

Research Student, Imperial Sugarcane Breeding Station, Coimbatore

(Received for publication on 21 June 1939)

(With Plates VII-XVI)

I. Introduction

TRIPLOIDY was first discovered in *Oenothera* [Gates, 1908] and since then has been reported in many genera of plants [Darlington, 1937]. Triploids include two groups, the auto-triploids that have three identical genoms, the chromosome complement of which can be represented as of the constitution **AAA**, **BBB** and so on, and the allotriploids that have sets of chromosomes that are not identical and which could be represented as that of the constitution **AAB** or **ABC**.

Triploids in general may originate in three different ways: (1) through an abnormality in somatic mitosis in the haploid generation such as splitting of chromosomes or reunion of daughter nuclei, (2) through failure of reduction at meiosis and consequent fusion of unreduced ($2n$) and reduced (n) gametes and (3) by hybridization between diploids and tetraploids.

One of the features associated with the cytology of reproduction in *Saccharum* is the phenomenon of doubling in the chromosomes of the pistillate parent of interspecific crosses first reported by Bremer [1923] in natural hybrids between *S. officinarum* var. Black Cheribon ($n=40$) and *S. spontaneum* Glagah ($n=56$). The same feature was observed in crosses between *S. officinarum* var. *vellai*, and other varieties of *S. spontaneum* [Dutt and Rao, 1933; Janaki Ammal, 1938, 2], and in several intergeneric crosses effected at Coimbatore.

Bremer considers this doubling of the chromosomes in *S. officinarum* parent, a phenomenon characteristic of interspecific hybridization in *Saccharum* the doubling having occurred in the egg cell during fertilization. Triploids have, however, been found to occur among selfed progenies and intraspecific hybrids of *S. spontaneum* [Janaki Ammal, 1936]. This fact and the presence of abnormal binucleate pollen grains occasionally seen in *S. officinarum* lead one to think that the method of doubling may not be quite as simple as Bremer imagined. The present investigation was, therefore, taken up to discover the exact method of chromosome doubling associated with the cytology of reproduction in *Saccharum*.

II. Material and methods

The two species of *Saccharum* selected for investigation were :—

(1) *S. spontaneum* from Dehra Dun ($2n=56$);

(2) *S. officinarum* var. *vellai* of Coimbatore ($2n=80$).

*A thesis approved for the Degree of Master of Science by the University of Madras.

Of these, *S. spontaneum* was a variety raised from seeds sent by Mr Holes from Dehra Dun in the year 1912 and since propagated by cuttings or 'setts' at the Imperial Sugarcane Breeding Station, Coimbatore. *S. officinarum* var. *vellai* is a thick cane grown in Coimbatore district. This cane is male-sterile and has been used extensively at the Coimbatore Sugarcane Breeding Station for hybridization with *S. spontaneum*, *Sorghum* and other genera of grasses and it has been the pistillate parent of the first cross made between *S. officinarum* and *S. spontaneum*.

Fixations were done during the months of August-October in the year 1937. Root-tips were fixed at 11 A.M. in Navashin's fixative [McClung, 1937] and in Medium Flemming; and the young spikelets fixed between 8 and 11 A.M. in Navashin's and Bouin's fluid (as modified by Allen) after prefixation in Carnoy's for a minute. Fixations were made at all stages ranging from divisions in pollen-mother-cells to fully formed pollen grains. Preliminary examination of anthers in acetocarmine [Belling, 1926] was resorted to for selecting right stages. For the study of embryo formation in *S. officinarum*, flowers of *vellai* were artificially pollinated by the Coimbatore form of *S. spontaneum* ($2n=64$) under bag. Spikelets of flowers thus pollinated were fixed in acetic alcohol at intervals of two hours during the first day and at intervals ranging from three to four hours, for a week after pollination. The materials were left in the fixing fluid for 24 hours. Root-tips and flower buds were then washed in several changes of tepid water for three to four hours and mature ovules (fixed in acetic alcohol) in 70 per cent alcohol. Callus hairs and glumes were clipped off the spikelets so as to facilitate sectioning. Dehydration and embedding were done according to La Cour's [1937] schedule.

Sections of root-tips were cut 10μ, flower buds 13μ to 15μ and mature ovules 25μ to 30μ thick. Sections of root-tips fixed in Medium Flemming were bleached in a mixture of three parts 70 per cent alcohol and one part 20 volumes hydrogen peroxide. Sections were stained in Haidenhain's iron-alum-haematoxylin with picric acid as destainer and also in Newton's Gentian Violet-iodine.

All drawings were made with a Spencer Abbé Camera Lucida at stage level. An apochromatic objective 100 (N. A. 1. 3) was used with different eye-pieces to give approximate magnifications indicated below the figures.

III. Somatic chromosomes

Fifty-six chromosomes could be counted at the somatic metaphase of *S. spontaneum* Dehra Dun (PlateVII, fig. 1), thus confirming the count made by Janaki Ammal [1936] for this variety of *S. spontaneum*. In root-tip sections of *S. officinarum* var. *vellai*, the chromosome counts showed the somatic number to be 80, characteristic of *S. officinarum* [Bremer, 1923] (Plate VII, fig. 2). The two species studied showed gradations of size in the chromosome complement. Measurements taken from good metaphase plates showed that the average length of the longest chromosomes in *S. spontaneum* was about 2·8μ while that in *S. officinarum* 3·6μ. The long chromosomes of *S. spontaneum* corresponded in length to that of the medium ones in *S. officinarum*. The short chromosomes in the two species showed an average length of 1·6μ and

were almost identical. The chromosomes of *S. spontaneum* fall approximately into three different types, long, medium and short, according to their length, and could be represented as 8L+32M+16S, while in *S. officinarum*, four types could be distinguished. These can approximately be classified into 10L+20M+30m+20S.

Both primary and secondary constrictions were found in the long chromosomes. Trabants have not been observed in the chromosomes of the two species of *Saccharum* investigated.

IV. Observations on divisions in megaspore-mother-cells of *S. spontaneum* and *S. officinarum*

The archesporial cell in *S. spontaneum* is differentiated early from a group of cells at the apex of the floral axis. It is found to be sub-epidermal in origin and covers nearly a third of the nucellar tissue (Plate VII, fig. 3). It is characterized by having larger nucleus and richer cytoplasm in the resting condition, than those in the surrounding cells. This cell functions as the megaspore-mother-cell without any further divisions as observed in other grasses like *Triticum* [Percival, 1921], *Poa* [Anderson, 1927], *Oryza* [Teradu, 1928], *Zea* [Randolph, 1936] and *Euchlaena* [Cooper, 1937]. The nucellar epidermis immediately above the archesporial cell becomes two-cell thick.

As prophase advances in the nuclei of megaspore-mother-cells, the leptotene threads were found to contract, their uneven granular structure becoming increasingly evident. Polarization of the threads were observed in fixed materials examined at this stage, their free ends being directed to one side of the nucleus towards the micropylar end (Plate VII, fig. 4). The association of chromosomes seen at prophase stage was found to be parasynaptic as also observed in pollen-mother-cells of the plant [Janaki Ammal, 1936], a feature that has now been recognized as universal in meiosis [Darlington, 1931]. It is surprising that Santos [1937] finds the telosynaptic type of chromosome association and the presence of a continuous spireme in the pollen-mother-cells of the Philippine variety of *S. spontaneum* he examined! Terminalization of chiasmata was minimum in the long chromosomes and the chiasma behaviour in megaspore-mother-cells was found to approximate very closely that in pollen-mother-cells of the plant [Janaki Ammal, 1936].

Twenty-eight bivalents could be counted at late diplotene and diakinesis (Plate VII, figs. 5 and 6) each pair being held together by chiasmata. The three types of lengths noticed in somatic chromosomes could be fairly distinguished at meiosis.

In megaspore-mother-cells of *S. officinarum*, 40 bivalents could be counted at diakineses (Plate VII, fig. 7) though occasionally thirty-nine bivalents with one or two univalents were also seen. The bivalents were found paired by chiasmata which varied from one to two in cells examined at diplotene and diakinetic stages. Both terminal and interstitial chiasmata were observed in megaspore-mother-cells. These observations were found to be similar to those on pollen-mother-cells of the same species (Plate VII, fig. 8). A normal bipolar spindle (Plate VII, fig. 9) was observed in both the species. Secondary association of the chromosomes was well marked at the metaphase stage of division. During anaphase stage in megaspore-mother-cells of *S. officinarum*,

were almost identical. The chromosomes of *S. spontaneum* fall approximately into three different types, long, medium and short, according to their length, and could be represented as 6L+12M+10S, while in *S. officinarum*, four types could be distinguished. These can approximately be classified into 10L+20M+30m+20S.

Both primary and secondary constrictions were found in the long chromosomes. Trabants have also been observed in the chromosomes of the two species of *Saccharum* investigated.

IV. Observations on megaspore-mother-cells of *S. spontaneum* and *S. officinarum*

The archesporial cell in *S. spontaneum* is differentiated early from a group of cells at the apex of the floral axis. It is found to be sub-epidermal in origin and occurs usually a third of the nucellar tissue (Plate VII, fig. 3). It is characterised by having larger nucleus and richer cytoplasm in the resting condition than those in the surrounding cells. This cell functions as the megaspore-mother-cell without any further divisions as observed in other grasses like *Tritium* (Percival, 1921), *Zea* [Anderson, 1927], *Oryza* [Teradu, 1928], *Sorghum* (Randolph, 1932), *Eschscholtzia* [Cooper, 1937]. The nucellar epidermis sometimes also functions as archesporial cell becomes two-cell thick.

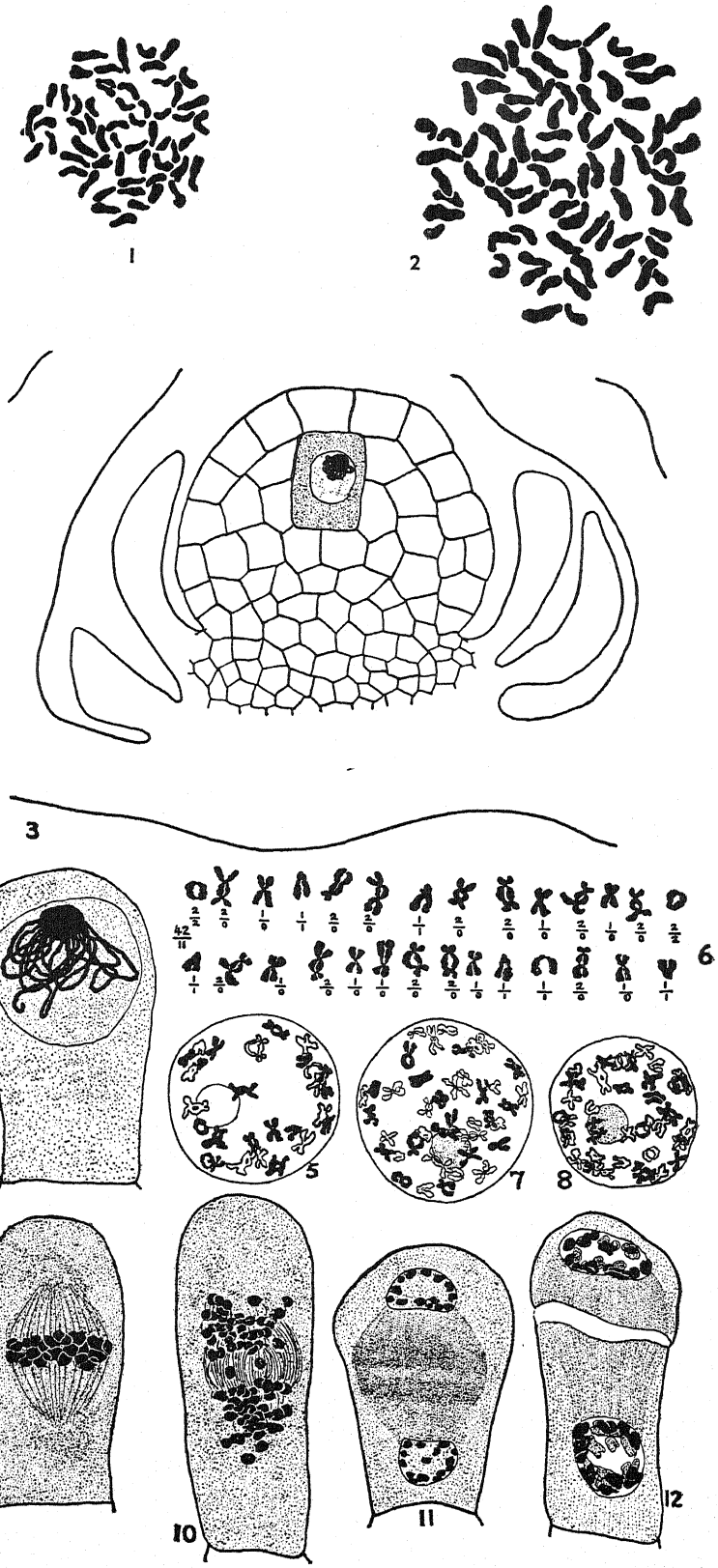
PLATE VII

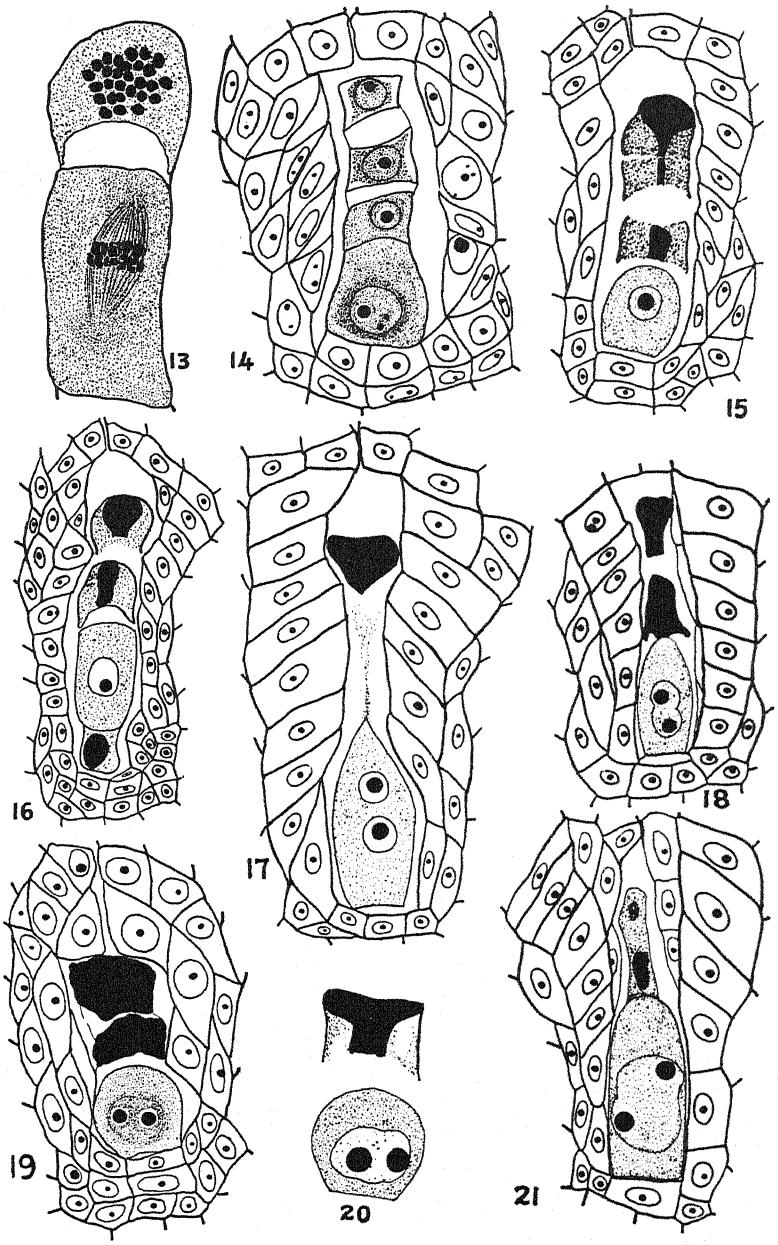
1 & 2: Mitotic metaphases in root-tip cells of *S. spontaneum* (2*n*=56) and *S. officinarum* (2*n*=80) (magnified); 3: Subepidermal archesporial cell in nucellar tissue (×500); 4: Polarisation at leptotene stage (× 1500); 5: Diakinesis showing 28 bivalents (× 1875); 6: Configuration of bivalents from one megaspore-mother-cell at diakinesis (× 1875); 7: Diakinesis in m.m.c. of *Saccharum officinarum* showing 40 bivalents (× 1875); 8: Diakinesis in p.m.c. of *vellai* (× 1875); 9: First Division Metaphase —side view (× 1500); 10: First Division Anaphase in m.m.c. of *vellai*, showing the univalents separating to the poles (× 1500); 11: Late telophase of first division in m.m.c. of *S. spontaneum* (× 1500); 12: Dyad cells after the first division of megaspore mother-cell (× 1500)

Behaviour of the nucleoli of megaspore-mother-cells, the [illegible] meiosis [Darlington, 1932]. It is worthwhile that Santos [1937] finds the telosynaptic type of [illegible] and the presence of a continuous spireme in the pollen-mother-cells of the Philippine variety of *S. spontaneum* he examined. Terminalization of chiasmata was minimum in the long chromosomes and the chiasma behaviour in megaspore-mother-cells was found to approximate very closely that in pollen-mother-cells of the plant [Janaki Ammal, 1936].

Twenty-eight bivalents could be counted at late diplotene and diakinesis (Plate VII, figs. 5 and 6) each pair being held together by chiasmata. The three types of lengths noticed in somatic chromosomes could be fairly distinguished at meiosis.

In megaspore-mother-cells of *S. officinarum*, 40 bivalents could be counted at diakineses (Plate VII, fig. 7) though occasionally thirty-nine bivalents with one or two univalents were also seen. The bivalents were found paired by chiasmata which varied from one to two in cells examined at diplotene and diakinetic stages. Both terminal and interstitial chiasmata were observed in megaspore-mother-cells. These observations were found to be similar to those on pollen-mother-cells of the same species (Plate VII, fig. 8). A normal bipolar spindle (Plate VII, fig. 9) was observed in both the species. Secondary association of the chromosomes was well marked at the metaphase stage of division. During anaphase stage in megaspore-mother-cells of *S. officinarum*,


1
2
3
4
5
6
7
8
9
10
11
12



13: Second division metaphase in dyad cells of *S. spontaneum* (× 1500); 14: A linear tetrad of megaspores formed after the meiotic divisions (× 750); 15. Linear spore-tetrad showing the innermost functional megaspore (× 750); 16: A liner spore-tetrad showing the functional sub-chalazal megaspore (× 750); 17: Binucleate chalazal megaspore (× 750); 18: Fusion of the two megaspore nuclei with the outer two megaspores in a degenerate condition (× 750); 19: Chalazal fusion nucleus (diploid megaspore) in *S. spontaneum* with two degenerated megaspores (× 750); 20: 'Fusion nucleus' in *S. spontaneum* with an outer undivided and degenerated dyad (× 1500); 21: Fusion of two megaspore nuclei in chalazal cell in *S. officinarum* (× 750)

the forty chromosomes were seen separating to the poles and a tendency for one or two univalents to lag was perceptible in certain cells (P ate VII, fig. 10).

The anaphase and telophase stages were normal in both the species of *Saccharum*, and two dyad cells each with the reduced number of chromosomes were formed (Plate VII, figs. 11 and 12). Wall formation was, however, found to be somewhat delayed at the first division in *S. officinarum*.

The second division spindles formed in the two dyad cells in both the species were found to be in the same plane as the first division spindles. The 28 chromosomes were counted at second metaphase in *S. spontaneum* (Plate VIII, fig. 13) and a linear quartet of megaspores was observed at the end of second telophase (Plate VIII, fig. 14). As in other members of the Graminae the innermost of the tetrad was found to be functional, the rest degenerating (Plate VIII, fig. 15). Anderson [1927] finds that the topmost one may develop in *poa*. Occasionally, however, I find the outer of the two inner megaspores (sub-chalazal) to develop in *Saccharum* (Plate VIII, fig. 16).

When a large number of spikelets of both the species were examined at this stage, it was found that occasionally two inner or chalazal megaspore nuclei were enclosed in a common cell. Such binucleate megaspores (Plate VIII, fig. 17) are formed presumably through failure of cell wall formation at the close of the second telophase. They could be distinguished from two-nucleate embryo-sacs by their smaller size, and the presence of the degenerated megaspores at the top. The binucleate condition of the megaspore is also supported by the presence of fusion nuclei (Plate VIII, fig. 18) in preparations of later stages. Such 'fusion nuclei' each with two nucleoli of equal sizes enclosed in a common nuclear membrane (Plate VIII, figs. 19, 20 and 21) were found in both the species of *Saccharum* examined. The phenomenon of reunion of two megaspore nuclei at the chalazal end, was found to be more common in the variety Vellai of *S. officinarum*, than in *S. spontaneum*.

Irregularities in megaspore-mother-cells responsible for a number of deviations from the normal were also observed during the course of second division in both the species. Plate IX, fig. 22 shows a stage where the chromosomes of the upper dyad were found to be at metaphase, while those in the lower one had reached the poles. The bipolar spindle formed at second metaphase in the micropylar dyad was found to be almost at right angles to the longitudinal axis of the cell as in *Zea* [Cooper, 1937]. This could give rise to a T-shaped spore-tetrad in *S. spontaneum* as in *Triticum* [Watkins, 1925]. The upper of the two dyad cells was found to degenerate before second division (Plate IX, fig. 23) or to divide and give rise to two megaspores, both however degenerating later (Plate IX, fig. 24), or it started division, but degeneration set in before the completion of the process (Plate X, fig. 25). In such cases the inner dyad proceeded with the devlopment of embryo-sac with the haploid number of chromosomes (Scilla type [Schnarf, 1936] and Allium type [Maheshwari, 1937]). At the time when two megaspores have been formed by the division of the chalazal dyad, the nucleus of the upper one was either in a resting condition (Plate IX, fig. 26) or at the metaphase stage (Plate IX, fig. 27). In both the species of *Saccharum*, the cells on either side immediately surrounding the products of meiotic divisions were somewhat elongated suggesting a tracheidal function.

V. Development of embryo-sac

Observations on meiosis in megaspore-mother-cells have shown that the embroyo-sac development in both the species of *Saccharum* may originate in one of three ways :—

1. From one of the tetrad megaspores (normal type).
2. From fusion of two of the spore-tetrad.
3. From a single dyad cell (Scilla type [Schnarf, 1936] and Allium type [Maheshwari, 1937]).

Of these the more common form was the development from haploid megaspores and dyad cells. The stages of development of haploid and diploid megaspores followed the normal course.

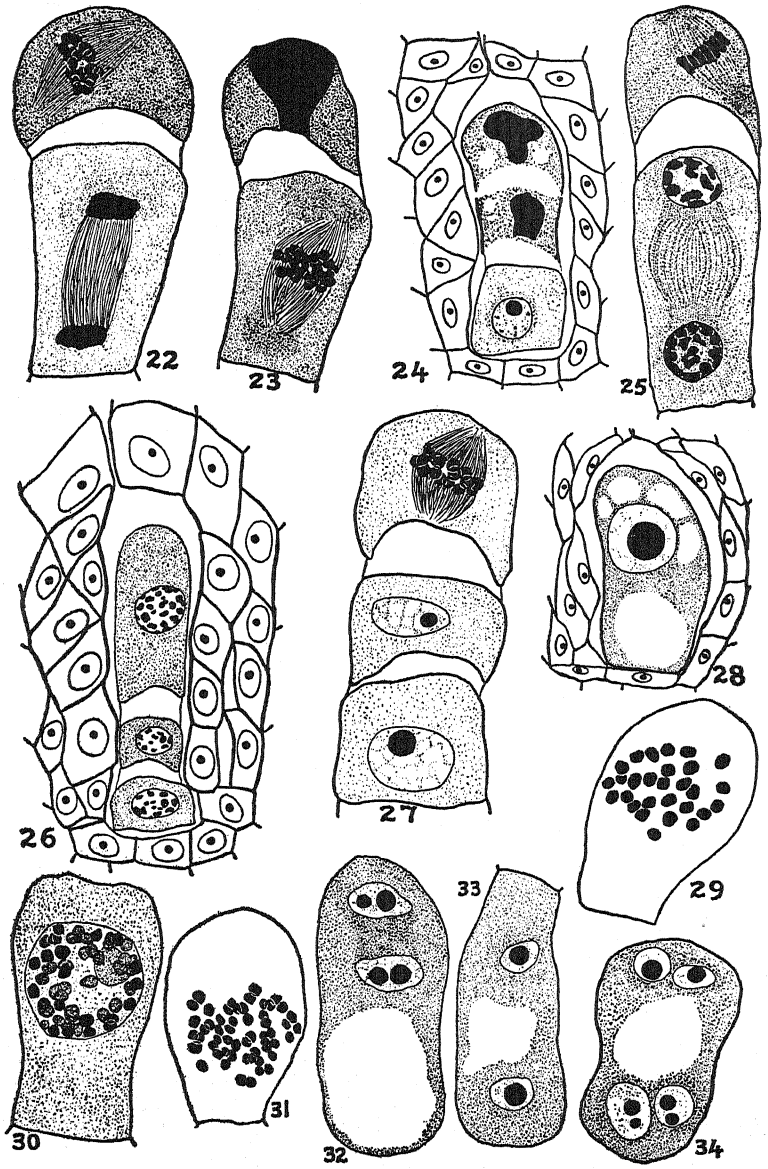
The first sign of embryo-sac formation from a megaspore was the enlargement of the megaspore often accompanied by vacuolization of the cytoplasm, the nucleus being pushed to the upper end (Plate IX, fig. 28). The 28 chromosomes could be counted at metaphase (Plate IX, fig. 29) in a large number of sections examined and the $2n$ number 56 in those arising from diploid megaspores (Plate IX, figs. 30 and 31). Secondary association was marked at this stage also.

The micropylar and chalazal poles of a developing embryo-sac were established by vacuolization at the centre. Considerable growth of the cell was noticed after this stage and could be easily differentiated from the binucleate megaspores. The eight-nucleate stage in the embryo-sac was derived by three normal mitotic divisions as in Plates IX and X, figs. 32-35, the egg-cell with its two synergids and a polar nucleus being differentiated at the micropylar end and the three antipodals at the chalazal end. The two polar nuclei were found to occupy a position just below the egg cell.

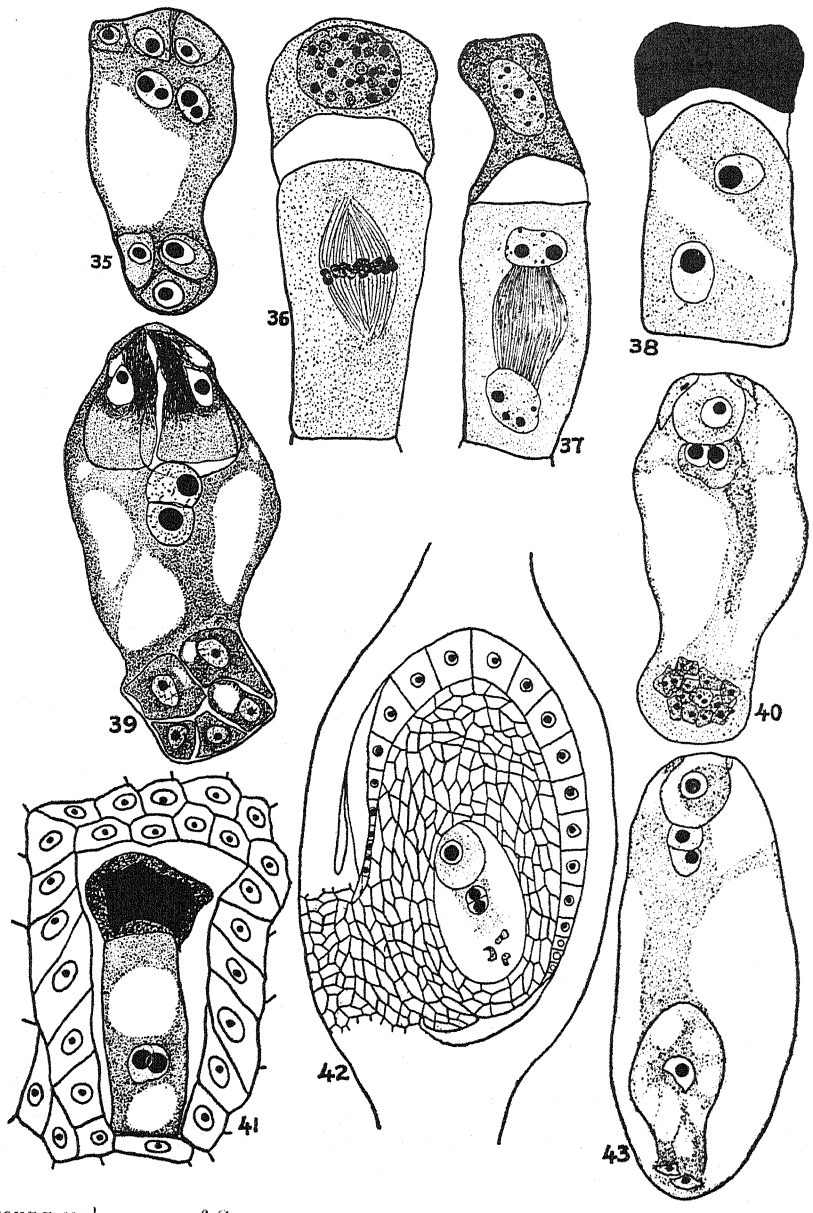
Development from haploid megaspore

The development from the haploid dyad cell as in *Scilla nonscripta* [Hoare, 1933] was found to be similar to that from the megaspore. The degeneration after the first division and before the second division of the micropylar dyad cell was observed and was found to persist as a darkly stained mass over the embryo-sac. In this type of development (Plate X, figs. 36, 37 and 38) the second division of meiosis represents the first mitotic division of embryo-sac formation, and the two processes merge into one another indistinguishably [Chiarugi, 1926 ; Schnarf, 1936 and Maheshwari, 1937]. The same type of development with a reduction in the antipodal cells at the chalazal end of embryo-sacs has been observed in *Alismaceae* [Dahlgren, 1928 ; Johri, 1935, 2, 3, 1936] and in species of *Allium* [Messeri, 1931 ; Jones and Emsweller, 1936].

In the fully-developed female gametophyte, the synergids showed longitudinal striations in the narrower end (Plate X, fig. 39). The synergids possessed also a hook or a beak. An antipodal tissue was derived by further divisions of the primary antipodal cells, as observed in several members of the Graminae like *Triticum* [Watkins, 1925 ; Wakakuwa, 1934-35], *poa* [Anderson, 1937], *Avena* [Kihara and Nishiyama, 1932], *Oryza* [Morinaga and Fukushima, 1934 and 1935], barley [Pope, 1937], *Zea* [Randolph, 1936 ; Cooper, 1937] and *Spartina* [Curtis, 1937]. In *S. spontaneum* this antipodal



22 : Non-identical stages of second division in m.m.c. of *S. spontaneum* (×1500) ; 23 : An outer degenerated dyad with an inner one showing the first mitotic metaphase of embryo-sac formation (×1500) ; 24 : A triad row of 3 megaspores showing the functional inner one (×750) ; 25 : Non-identical stages of second division of meiosis : the upper one shows signs of degeneration (×1500) ; 26 : Triads with two inner megaspores and an upper dyad (×1500) ; 27 : Late division of the upper dyad while the inner one has completed division (×1500) ; 28 : Embryo-sac cell of *S. spontaneum* with the resting nucleus (×750) ; 29 : First somatic metaphase of a haploid embryo-sac-cell of *S. spontaneum* showing the 28 chromosomes (×1500) ; 30 and 31 : Late prophase and metaphase stages of first mitotic division of a diploid megaspore showing 56 chromosomes (×1000) ; 32 and 33 : 2—nucleate embryo-sacs (×750) ; 34 : 4-nucleate embryo-sac. (×750).



35 : A young embryo-sac of *S. spontaneum* (×750) ; 36, 37 and 38 : Development of the chalazal dyad (Allium type) ; 39 : Synergids in a mature embryo-sac of *S. spontaneum* showing the filiform apparatus with a beak or a hook (×750) ; 40 : Embryo-sac of *S. spontaneum* showing antipodal tissue (×300) ; 41 : Fusion of daughter nuclei of the first mitotic division in an embryo-sac cell of *S. spontaneum* (×700) ; 42 : Reversal of embryo-sac in an ovule of *vellai* (×100) ; 43 : Embryo-sac of *vellai* showing an antipodal egg-cell (×250)

tissue was composed of 15 to 20 cells (Plate X, fig. 40). Such an aggressive type of tissue seems to be a primitive feature since reduction in gametophytic tissue is characteristic of the advanced members of angiospermous families.

The development of the female gametophyte in *S. officinarum* from megaspores and dyad cells was similar to that in *S. spontaneum*. The formation of a filiform apparatus associated with the synergids was not, however, characteristic of this species and the three antipodal cells were crescent-shaped in appearance. Each antipodal cell had a single nucleus, unlike that in *Zea* [Cooper, 1937],where two or more nuclei were observed, or in triploid *Oryza* [Morinaga and Fukushima, 1937] where as many as 17 nuclei in each antipodal cell have been reported.

VI. Abnormalities associated with embryo-sac formation in *Saccharum*

The following abnormalities were observed during the course of the investigation :—

1. Fusion of the daughter nuclei.—The two daughter nuclei formed after the first mitotic division in the developing dyad cell instead of separating to the poles, were found to fuse together. Plate X, fig. 41 represents such a fusion nucleus with the micropylar dyad in a degenerate condition. The cell in which a fusion was observed was three to four times as long and broad as the binucleate megaspores and was found to behave as a young embryo-sac. The embryo-sacs developed from such nuclei should all have a diploid chromosomal constitution. Thus a condition for the formation of $2n$ gametes was found in sporogenesis as well as during embryo-sac formation.

2. Reversal of normal embryo-sac.—Reversal of the normal embryo-sac, viz. the egg apparatus occupying the chalazal end and the antipodals the opposite end, was occasionally seen in *S. officinarum* var. *vellai* (Plate X, fig. 42). Such a feature has been reported in embryo-sacs of a cross between *vellai* × C A C 87 by Dutt and Rao [1933].

3. Secondary egg cells in embryo-sac.—Several abnormalities associated with the antipodal cells were observed. Occasionally one of the antipodal cells at the chalazal end of embryo-sacs of *S. officinarum* simulated an egg cell, the other two apparently forming the synergids (Plate X, fig. 43). The normal egg apparatus was also present at the micropylar end. Such duplicated egg cells in an embryo-sac would probably give rise to double embryos. Similar egg-like antipodal cells have been reported in *Allium nigrum* [Modilewski, 1931] and *Allium subhirsutum* [Messeri 1931]. The presence, at the micropylar end in embryo-sacs of *S. officinarum*, of an additional egg-cell with two polar nuclei, but with no trace of antipodals at the chalazal end, shows that they are transformed antipodal cells (Plate XI, fig. 44). Plate XI, fig. 45, shows a similar feature in *S. spontaneum* but as the three antipodals are also observed, twin egg cells in this case are probably derived by extra divisions of the nuclei, after the third mitosis of embryo-sac formation.

4. Binucleated antipodal egg.—An antipodal egg-cell in which two nuclei, probably derived by fusion of two antipodal cells, were found closely adhering to each other for fusion. In such cells one of the antipodals was found to simulate a synergid. The normal egg-apparatus at the micropylar end was then found to be in a degenerate condition (Plate XI, fig. 46).

5. Abnormal divisions of antipodal cells.—Unlike *S. spontaneum*, the three antipodals in *S. officinarum* rarely divide to form a tissue. However, the propensity for activity was evident in several ways. The three primary antipodal nuclei fused together and presented a swollen appearance (Plate XI, fig. 47) or the nucleus in each antipodal cell gave rise to several free nuclei without cell-wall formation (Plate XI, fig. 48). Plate XI, fig. 50 shows that two of the antipodal cells are enlarged, the third one by further divisions is seen to simulate an embryo. Later stages of these have, however, not been observed.

6. Secondary embryo-sacs.—Two embryo-sacs are sometimes observed embedded in the same nucellar tissue (Plate XI, fig. 50), as reported in *poa* [Anderson, 1927]. These probably arise from two functional megaspores. Seeds derived from such ovules would show twin seedlings on germination.

7. Parthenogenetic development of egg cell.—In sections of an unpollinated ovule of *S. officinarum* an embryo was found to have developed at the micropylar end (Plate XI, fig. 51). The two polar nuclei were still unfused and showed signs of disintegration.

8. Nucellar embryony.—Plate XI, fig. 52 shows a four to six-celled embryo formed by one of the cells of the nucellar tissue, in an ovule just at the time of pollination. It is highly probable that this embryo is formed apogamously.

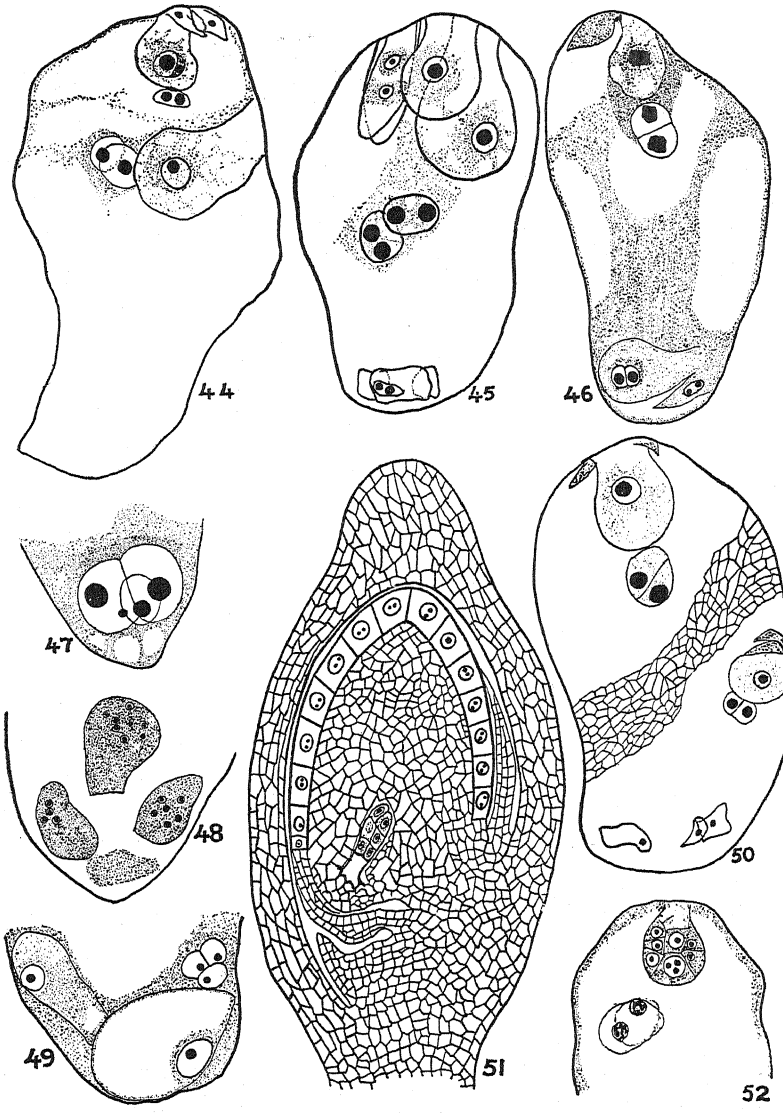
Plate XII shows a schematic representation of stages in divisions of megaspore-mother-cells and features in embryo-sac formation.

VII. Fertilization and embryogeny in *S. officinarum* pollinated by *S. spontaneum* ($2N=64$)

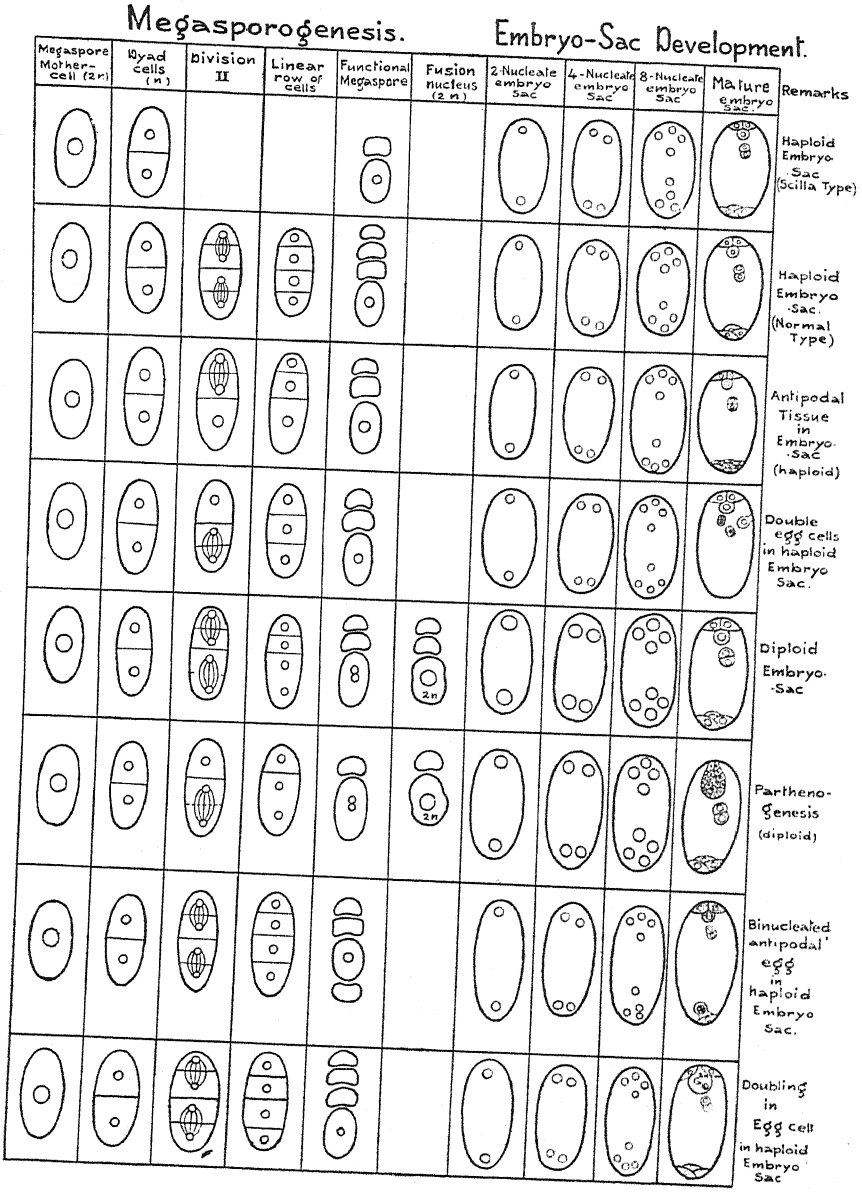
In ovules of *S. officinarum*, fixed just before pollination, the normal egg-cell was found to be pear-shaped, with the narrower end towards the micropyle (Plate XIII, fig. 53). The two polar nuclei were found in close proximity to the egg cell and were surrounded by rich cytoplasm. In one instance, the egg cell and synergids were found to be connected together by a peg-like growth from the latter which showed signs of degeneration. This phenomenon seems to indicate that the synergids function as suppliers of nutrients to the developing egg cell. The three antipodals were either prominent or showed signs of degeneration.

In materials fixed two hours after pollination with *S. spontaneum*, no apparent changes were observed in the embryo-sac. The volume of the egg cell, however, was found to have considerably increased in ovules fixed four hours after pollination. Starch grains and oil globules had formed around the egg nucleus. Six hours after dusting with pollen, pollen tubes were found growing between the integument and the pericarp (Plate XIII, fig. 54). Plate XIII, fig. 55 represents the section of an ovule at the same stage, in which the swollen tip of the pollen tube could be seen to have penetrated the embryo-sac with its two generative nuclei.

In a few of the sections examined, the cytoplasm in egg cell was found to be very granular forming a dense ring of chromatic substances round the egg-nucleus (Plate XIII. fig. 55). Similar chromatic bodies have been observed in *Triticum* by Watkins [1925] and *Eleusine* by Krishnaswami and Ayyangar



44 : Double egg cells at the micropylar end of an embryo-sac of *vellai* with 2 pairs of polar nuclei (×250) ; 45 : Embryo-sac of *S. spontaneum* showing the two egg cells of the micropylar end each with a separate pair of polar nuclei (×250) ; 46 : Binucleate antipodal egg in an embryo-sac of *vellai* with the normal egg apparatus in a degenerated condition (×250) ; 47, 48 and 49 : Abnormal antipodal cells (×250) ; 50 : Secondary embryo-sac in nucellar tissue in an ovule of *vellai* (×250) ; 51 : Nucellar embryo in an ovule of *vellai* (×100) ; 52 : Parthenogenetic development of an egg in *vellai* with the unfused polar nuclei showing signs of degeneration.



Course of megasporogenesis and embryo-sac development in *Saccharum*

[1937]. According to Watkins this ring may be the product of a synergid attacked by the entry of the pollen tube, or coagulation products of the cytoplasmic strands round the egg nucleus. Since degeneration of the synergids before fertilization is a feature commonly observed in this variety of *S. officinarum*, the latter explanation seems to be more likely. Plate XIII, fig. 56 shows the egg cell in the metaphase stage of division in an ovule in which the pollen tube has not penetrated the micropylar end. The two polar nuclei lay close to the egg cell.

Fertilization was found to take place about eight hours after pollination. Plate XIV, fig. 58 shows this condition of the ovule in which one of the male nuclei is found to fertilize the egg and the other one, the polar nuclei. As in other grasses, ferilization of the egg and polars was found to be simultaneous. Plate XIV, fig. 59 shows a united reticulated condition of the chromatic matter in the zygote. The zygote next undergoes a period of rest in which condition it had two nucleoli, one of which was smaller than the other (Plate XIII, fig. 57). These probably belong to the genom of the two parent *Saccharum* species.

The fusion of the two polar nuclei is found to precede their fertilization by the second male gamete as in *Triticum* [Watkins, 1925]. In *Zea*, however, it has been found that the male nucleus and one polar nucleus complete their fusion before they unite [Rhoades —quoted by Sharp, 1934]. The primary endosperm nucleus divides immediately after fertilization and at the first mitotic metaphase the chromosomes were found to approximate in number to 112 of which the haploid set of thirty-two is derived from the male parent.

The plane of the first division of the endosperm nucleus was in most cases almost parallel to the longitudinal axis of the embryo-sac. In sections of ovules examined 22 hours after pollination, a layer of free nuclear endosperm with four to eight nuclei was found to have surrounded the zygote. Later these were found to divide and a feature of the endosperm nuclei was that they showed in several cases identical mitotic stages (Plate XIV, fig. 65). Chromosome counts in good metaphase plates showed the triploid ($3n$) and the pentaploid ($5n$) nature of the endosperm nuclei in different embryo-sacs. Plate XIV, fig. 66 shows the metaphase plate of an endosperm nucleus in which more than 145 chromosomes could be counted. This probably represents a $5n$ endorsperm.

The first division of the zygote was found to occur in ovules fixed 32 hours after pollination (Plate XIV, fig. 60). In *Zea*, Randolph finds this to take place 30 hours after pollination, while in *Hordeum*, Pope [1937] finds the same condition 14 to 15 hours after. In *Avena* crosses, Kihara and Nishiyama [1932-33] report two to four celled stages of embryo, 24 hours after pollination. The division of the zygote nucleus in *Saccharum* was always transverse to the longitudinal axis of the embryo-sac resulting in a two-celled embryo (Plate XIV, fig. 61).

The epibasal cell formed a suspensor of four to five cells (Plate XIV, fig. 69), and the basal cell was divided into two by a longitudinal or oblique cell plate (Plate XIV, figs. 62 to 64). By further cell divisions the pro-embryo assumed a globular shape (Plate XIV, fig. 67), a cross-section of which is shown in Plate XIV, fig. 68 from sections cut at this stage. The developing embryo

was found to be surrounded on all sides by free nuclear endorsperm which became cellular in later stages of development.

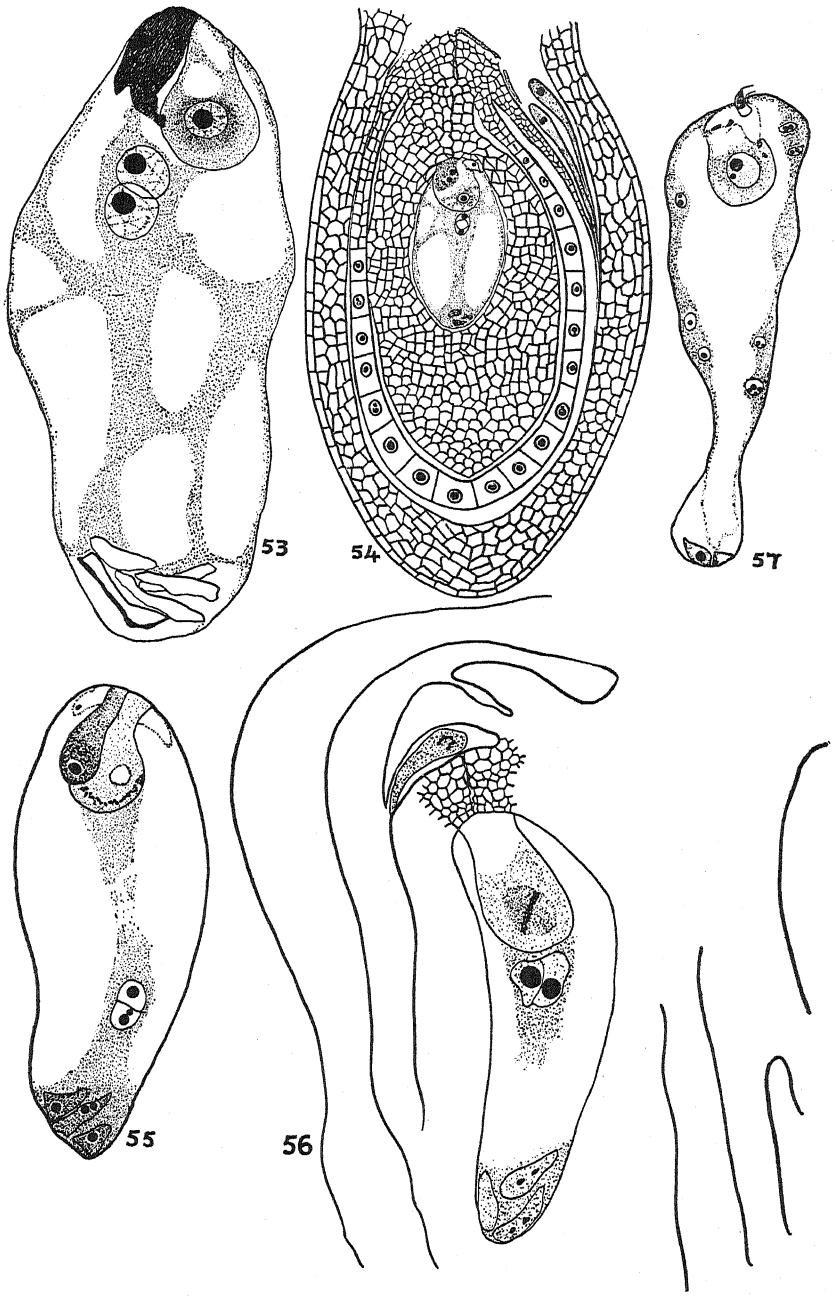
The rest of the development of the embryo in *Saccharum* was also found to be similar to that in other grasses. Observations on sections of ovules showed a marked difference in size between the embryos at the four-celled stages. A regularity in the sequence of divisions in the pro-embryo was also noted especially in the small-sized ones. The axis of development of the young embryo was found to be indicated by a central patch of cells that show bigger nuclei with richer cytoplasm than those in the surrounding cells (Plate XIV, fig. 70). Disorganisation of the antipodal cells was found to take place simulatenously with the formation of endosperm [Artschwager *et al.*, 1929]. The antipodal tissue in *Zea* and *Coix* occasionally retains its activity even up to the time the seed is mature [Weatherwax, 1930 ; Randoplh, 1936] while in *Poa*, the antipodals persist till late in the endosperm formation and then degenerate.

VIII. Discussion

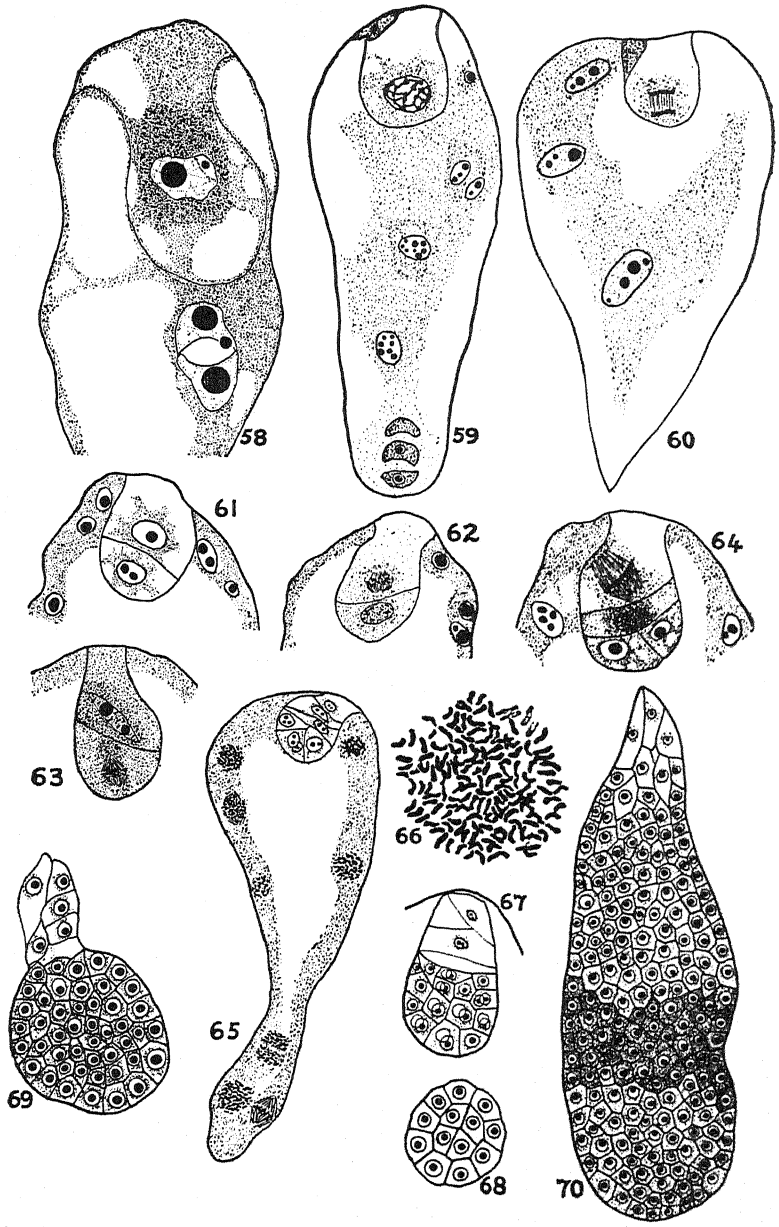
(*a*) *Production of triploids and the condition of polyploids in* Saccharum

The most widely prevalent method of triploid formation in flowering plants has been traced to the union of gametes that have a diploid and haploid chromosomal constitution. Direct cytological evidence for the origin of a triploid through an unreduced female gamete being effective in fertilization, has, as Sansome and Philp [1932] have observed, been rather meagre in most cases. More often the evidences for such are based on genetical studies Triploid progenies through fusion of n and $2n$ gametes (arising presumably through irregularities in meiosis) have been reported in a large number of plants as in *Crepis* [Navashin, 1929], *Nicotiana* [Brieger, 1928], *Rosa* [Erlanson, 1929, 1933 and 1934], *Galeopsis* [Müntzing, 1930], *Musa* [Cheesman, 1931], *Gossypium* [Skovsted, 1934], *Veronica* [Graze, 1935], *Delphinium* [Lawrence, 1936], *Vitis* [Olmo, 1937], *Lolium* [Jenkins and Thomas, 1938], etc. Backcrossing the F_1 progenies with one of the parents has resulted in the production of triploid plants in *Raphano-Brassica* [Karpechenko, 1927] and *Nicotiana* [Lammerts, 1929]. Allo-triploids have also been obtained in intergeneric crosses between *Zea*, *Tripsacum* and *Euchlaena* [Manglesdorf and Reeves, 1935]. A triploid radish × turnip hybrid has risen through functioning of diploid radish egg cell [Morris and Riccharia, 1937].

In most of the plants in which triploidy has been observed, the plants are either diploids or lower polyploids. *S. officinarum*, with $2n=80$ chromosomes, represents an octoploid with a basic number ten, while *S. spontaneum* ($2n=56$) has been considered to be a dibasic octoploid [Janaki Ammal, 1939]. My observations show that triploids are produced in *Saccharum* through a diploid egg cell being effective in fertilization. Such triploids differ from the normal ones in that their haploid number of chromosomes already represent a high ploypoid condition. They are, therefore, ' triplo-polyploids ' [Janaki Ammal, 1939] and similar to the mutant triploids occurring in secondary polyploids like *Pyrus* [Darlington and Moffett, 1930 ; Hailborn, 1935].



53: Mature embryo-sac of *vellai*: a peg-like growth from the synergids is seen to connect the egg cell (×400); 54: Shows pollen tubes growing between the integument and pericarp: one is seen to have penetrated the micropyle with its two generative nuclei (× 100); 55: Embryo-sac showing dark bodies deposited round the egg nucleus during the entry of pollen tube (× 250); 56: Embryo-sac of *vellai* showing the egg nucleus at metaphase stage of division before the penetration of pollen tube (× 250); 57: Zygote showing 2 nucleoli of different sizes and surrounded by free nuclear endosperm (× 250)



58: Fertilisation of the egg and polar nuclei (× 400); 59: Embryo-sac showing zygote nucleus in a united reticulated condition (× 250); 60: Anaphase of first division of zygote nucleus (× 200); 61: Two-celled embryo (× 375); 62, 63, 64: Show the development of the embryo (× 375); 65: An embryo surrounded by free-nuclear endosperm in identical mitotic stages of division (× 300); 66: Metaphase plate of an endosperm nucleus showing 144 chromosomes (× 1500); 67: An embryo globular in shape (× 250); 68: Cross section of an embryo at the stage shown in Fig. 64 (× 250); 69: Globular embryo with a suspensor of 4—5 cells (× 200); 70: A mature embryo showing differentiation of a central patch of cells marking off the axis of further development (× 200)

Cytological studies by Bremer in the hybrid '*Kassoer*', obtained from crosses between *S. officinarum* var. Black Cheribon ($2n=80$) and the wild *Glagah* (*S. spontaneum*) at Java ($2n=56$), revealed that 68 bivalents are formed at diakinesis and metaphase stages of first division in pollen-mother-cells. The plant showed 136 chromosomes in somatic cells instead of the expected number 96. This duplication of the monoploid set of chromosomes occurred in *S. officinarum*, the pistillate parent. In none of his preparations of *S. officinarum* at reduction divisions in megaspore-mother-cells, was he able to find a single instance of non-reduction. This led Bremer [1923, 1929] to conclude that the phenomenon of doubling of chromosomes in the female, is characteristic of species hybridization in *Saccharum*, doubling taking place 'by a longitudinal splitting of chromosomes in egg cell, the chromosomes of *S. spontaneum* remaining unsplit'. The production of autotriploids among selfed seedlings and triploid hybrids among interaspecific crosses between different chromosomal types of *S. spontaneum* [Janaki Ammal, 1938, 2] show that causes other than species hybridization are responsible for the origin of triploids in this genera of grasses.

(*b*) *Formation of* 2n *gametes in* Saccharum

Various irregularities during meiosis or in premeiotic divisions in archesporial cells have been found to lead to non-reduction and development of unreduced gametes. Thus retardation or suppression of first division has been observed in *Papaver* [Ljungdah, 1922] and *Taraxacum* [Gustaffson, 1935], and nullification of first or second division has been found in plants like *Prunus* [Darlington, 1930], and *Hieracium* [Rosenberg, 1927]. Double division of univalents, associated with complete failure of pairing at metaphase found in moth hybrids [Federley, 1931], have not been commonly observed in flowering plants, though found to occur sporadically in *Ribes* [Meurman, 1928]. Ramanujam [1937], however, reports such a feature to occur in pollen-mother-cells of F_1 hybrids of *Oryza*. Syndiploidy as found in anthers of *Ochna* [Chiarugi, 1930], *Lactuca* [Gates and Rees, 1921], *Triticum* [Gaines and Aase, 1926], *Zea* [McClintock, 1929], *Avena* [Nishiyama, 1931; Ellison, 1937] and *Chrysanthemum* [Shimotomai, 1931] have not been observed in archesporial cells in ovules.

Though similar abnormalities were expected in megaspore-mother-cells of *Saccharum*, my observations have shown that normal reduction division occurs in both the species giving rise to a spore-tetrad or a triad row of three cells, viz. an undivided dyad and two megaspores. A reunion of two megaspores that have each a haploid set of chromosomes leads to the formation and development of diploid megaspores in both the species of *Saccharum*. That the two nuclei fuse together is evident by the presence of 'fusion nuclei' found to be formed in a common cell at the pollen grain stage in anthers. A similar reunion of daughter nuclei was also observed after the first mitosis of embryo-sac formation from a haploid dyad cell, a feature interpolated in the course of a Scilla type of development. Such 'fusion nuclei' are found to give rise to diploid embryo-sacs, as the duplicated number of chromosomes could be counted at the first somatic metaphase of embryo-sac formation.

The occurrence of triploid ($3n$) and pentaploid ($5n$) endosperm show that normal and diploid female gametophytes are effective in fertilization in both the species of *Saccharum*. It follows, therefore, that triploid embryos are produced by fertilization of the diploid eggs, and have resulted in the production of autotriploids in *S. spontaneum* and hybrid triploids in *S. officinarum* pollinated with *S. spontaneum*. It is highly probable that the larger embryos represent such triploid ones.

Reunion of daughter nuclei in the haploid generation has also been observed in *Saccharum*, at the chalazal end in embryo-sacs, giving rise to diploid cells simulating eggs. Such diploid egg cells on fertilization could also give rise to triploid embryos. They might also develop parthenogenetically.

Division of the mature egg at the time of fertilization was observed only in a single instance. This probably represents a doubling of chromosomes presumed by Bremer [1923]. According to him such a splitting of chromosomes is a result of the stimulus of fertilization Midusima and Saito [1937] give the same explanation for the origin of triploid *Brassica-Raphanus* hybrids. Newton [1927] observed a doubling of chromosomes at the chalazal end in the second division of meiosis, in embryo-sacs of the Leiostemones section of *Tulipas*. On two occasions, in *T. Kolpakowskiana*, he also observed its occurrence at the micropylar end. Such a doubling was remarkable in every fertilized ovule in the capsule and the frequent production of autotriploids among *Tulipas* have been explained in this manner [Darlington, 1937].

However, my observations on the species of *Saccharum officinarum* and *S. spontaneum* show that doubling of chromosomes takes place more often during gametogenesis than fertilization. This feature does not conform to any of the hitherto described types of meiotic irregularities leading to non-reduction, unless we consider this fusion of an already divided dyad as equivalent to ' the nullification of second division '. My observations also show that the same causes that produced autotriplody in *S. spontaneum* are found to be responsible for the origin of interspecific triploids between *S. officinarum* and *S. spontaneum*.

(c) *Time relationships in meiosis*

Non-simultaneous divisions in dyad cells of pollen-mother cells have been reported in a number of grasses like *Eleusine*, *Oryza*, etc. Observations on divisions in megaspore-mother-cells in *Saccharum* show that nuclear and cell divisions in the inner or chalazal dyad always precede division in the outer or micropylar dyad cell. This delaying of cell division in the upper one has also been found to result in its complete degeneration. Immediately after the first division, the lower dyad is found to increase in length by further growth, whereas the upper one remained without any change. The second divison spindle in the upper dyad was also found to be defective in certain cases. In *Saccharum*, therefore, could be observed an irregularity due to timing and spacial adjustment, brought about by a lack of coordination of certain external and internal agents of cell division. Such a condition may be the outcome of a nutritional advantage of the innermost megaspores of a

linear tetrad, being in immediate contact with the floral axis. This condition does not arise in pollen-mother-cells.

(*d*) *Parthenogenesis in* Saccharum

It has been found that ordinarily the egg cell in normal embryo-sacs develops into an embryo only after fertilization. Several plants have, however, been known to develop haploid embryos by influence of certain external stimuli like electrical, chemical and mechanical injuries inducing the unfertilized egg to develop. Haploids have been produced by selfing in *Nicotiana* [Webber, 1933; Goodspeed and Avery, 1930], and *Solanum* [Humphrey, 1934] or pollination with a different species as in *Datura* [Belling and Blakeslee, 1927] and *Solanum* [Jorgensen, 1928]. Heat treatment as in *Zea* [Randolph, 1932] or dusting with X-rayed pollen as in *Triticum* [Kihara and Katayama, 1932; Katayama, 1935, and Chizaki, 1934] have also been found to induce parthenogenesis. In plants like *Allium odorum* [Modilewski, 1930] and certain species and biotypes of *Potentilla* [Müntzing, 1928], parthenogenesis has been induced by pseudogamy, viz. the male gamete merely exciting the development of the egg and then degenerating.

Gaines and Aase [1926] found that haploid *Triticum compactum* arose parthenogenetically following the fusion of both the male gametes with the polar nuclei. According to Haberlandt [1921] the stimulus of degeneration of synergids and nucellar tissue has induced parthenogenesis in *Taraxacum* and *Hieracium*. It has been found that diploid parthenogenesis in species of *Chondrilla* [Poddubnaja-Arnoldi, 1933] and *Taraxacum* [Gustaffson, 1934] has been associated with meiotic irregularities like the formation of restitution nuclei leading to non-reduction and development of unreduced gametes. In *Artemisia nitida* [Chiarugi, 1926], such diploid embryos are produced parthenogenetically in gametophytes developed from a single diploid megaspore as in *Hieracium* and *Antennaria* [Bergman, 1935], and *Poa serotina* [Kiellander, 1935], from one of the diploid dyads as in *Taraxacum* or from one of the tetrad diploid megaspores (*Alchemilla* type).

Since in *S. officinarum*, embryo can develop in unpollinated ovules, the reunion of two megaspores after a normal reduction has to be considered in the light of a 'fertilization'. It is, therefore, in result identical with the sexual fusion of gametes. This fused nucleus (with the constitution of a zygote) develops into a diploid gametophyte, in which one of the nuclei divides to form an embryo at the micropylar end.

The degeneration of the two polar nuclei associated with parthenogenesis is a noteworthy feature in *S. officinarum*. In species such as *Erigeron annus* [Holmgren, 1919], the two may fuse or, as in *Balanophora* [Ernst, 1914], may not fuse. In *Zephyranthus* [Pace, 1913], however, an endosperm tissue was formed by fusion of both the polar nuclei with a generative nucleus.

Nucellar embryony, viz. one of the cells of the nucellus directly developing into an embryo, was found in unpollinated ovules of *S. officinarum*. A similar feature by stimulation of pollination has been observed in *Allium odorum* [Haberlandt, 1923], and in *Zygopetalum Mackayi* [Suessenguth, 1923]. Mangelsdorf and Reeves [1931] observed many parthenocarpic ovaries in *Zea* (♀) × *Tripsacum* (♂) in which the nucellar cells were growing.

In parthenogenetic development in *S. officinarum*, the two polar nuclei which are found in a degenerate condition probably supply the egg with nutrients. In *Crinum* [Tomita, 1931], it has been found that embryo develops without endorsperm formation. Such embryos probably derive nutrients by destroying and absorbing the contents of nucellar cells. Thus failure of endosperm formation that would nourish the embryo seems to be made good by the egg cells deriving food materials from synergids, polar nuclei, antipodal cells and surrounding nucellar tissue.

(*e*) *Polyembryony*

Multiple embryos have been known to develop from cells of nucellus, synergids, antipodal cells, suspensor cells and cells of the integument. This polyembryony has been reported in grasses like wheat, oats and rye [Hansen, 1920—1921], rice [Komuro, 1922; Rodrigo, 1925; Jones, 1928]. In ovules of *S. officinarum*, double egg cells in embryo-sacs and secondary embryo-sacs as in *Poa*, *Oryza*, etc. developed from more than one megaspore-mother-cell have been observed. These provide the conditions for the production of twin seedlings. Twin seedlings of *Triticum*, *Secale*, *Avena*, *Phleum*, *Poa*, *Festuca*, etc. have shown deviating chromosome numbers one of the twins generally showing to be a triploid [Müntzing, 1937]. It is possible that such seedlings in *Saccharum* would show their normal and polyploid nature as observed in wheat by Namikawa and Kawakami [1934].

(*f*) *Zygotic viability and incompatibility*

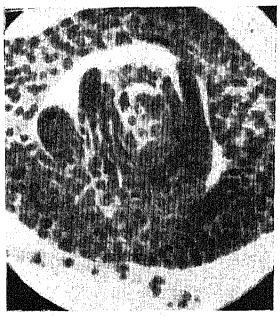
Thompson [1930], Weatherwax [1930], Kihara and Nishiyama [1931], Watkins [1932] and Müntzing [1933] are of opinion that there exists a relationship between three mutually dependant and genetically dissimilar tissues in a developing ovule, viz.: (*a*) the maternal tissue or nucellus and integuments, (*b*) the filial sporophyte—the embryo, and (*c*) the endosperm. The numerical relationship between the mother, endosperm and embryo in a normal diploid plant is as 2 : 3 : 2, or in other words, the diploid embryos are in contact with triploid endosperm amidst diploid soma or maternal tissue; hence the tissues are in equilibrium and give viable seeds. According to them, a lack of harmony in the physiology of the embryo and pistillate plant, as a result of quantitative change alone, would result in a retarded growth of embryo and do not form viable seeds. In a diploid embryo-sac, all the eight nuclei have the same relative constitution as in a normal haploid one. The $3n$ embryo developed on fertilization of diploid egg is in contact with $5n$ endosperm and is nourished by the $2n$ sporophyte. This ratio does not seem to interfere with the viability of the developing embryo, since the competing system forms '*eine vitele Konstallation*' as observed by Müntzing [1930-31].

If doubling of chromosomes were to occur in haploid egg cell of *S. officinarum*, it does not lead to a regular chromosomal balance between the different tissue systems, as the triploid embryo resulting from fertilization would be in contact with a $3n$ endosperm. This may probably account for the presence of degenerated embryos observed in a considerable number of ovules and for the high mortality of embryos generally observed in sugarcane as reported by Artschwager *et al.* [1929].

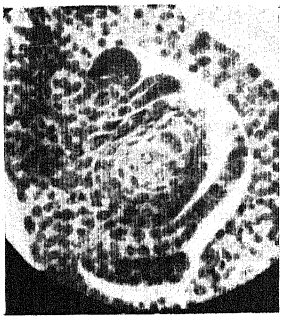
Plate XV

(Microphotographs taken at a magnification (×266) and 5″ extension of bellows)

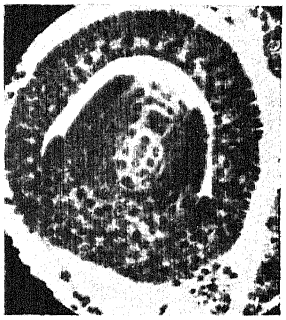
(*a*) Diakinesis in m.m.c. of *S. spontaneum*; (*b*) Dyad cells formed after first division of meiosis; (*c*) Non-identical stages of second division; (*d*) Triads; (*e*) Second metaphase in inner dyad cell with the upper one in a degenerate condition; (*f*) Linear spore-tetrad showing the functional chalazal megaspore; (*g*) Binucleate megaspore with two outer degenerate ones; (*h*) Two-nucleate embryo-sac; (*i*) Mature embryo-sac at the time of fertilization: a connection between egg-cell and synergids by a peg-like growth is seen; (*j*) Parthenogenetic development of egg in *vellai*; (*k*) Metaphase stage of division of egg cell before fertilization: the two polar nuclei are seen in tact; (*l*) Binucleate antipodal egg in an embroy-sac of Vellai.



a



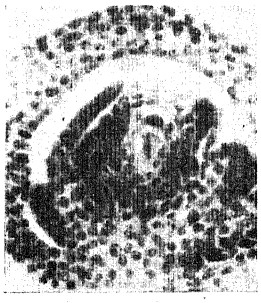
b



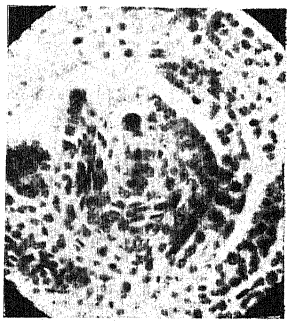
c



d



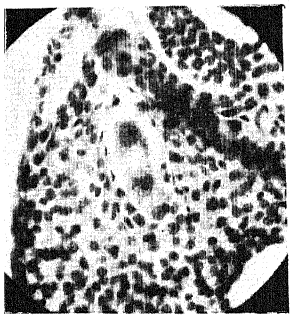
e



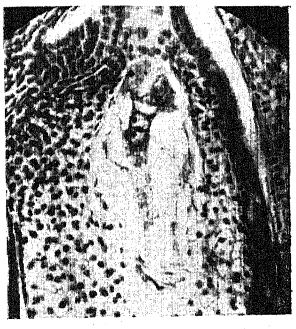
f



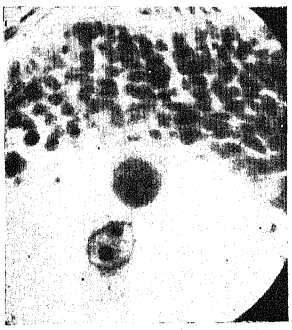
g



h



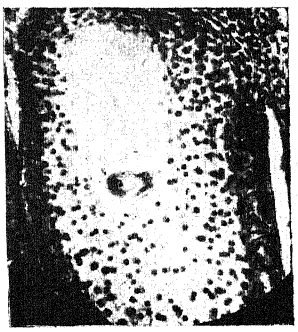
i



j



k



l



a



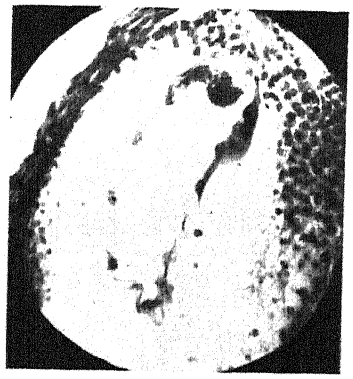
b



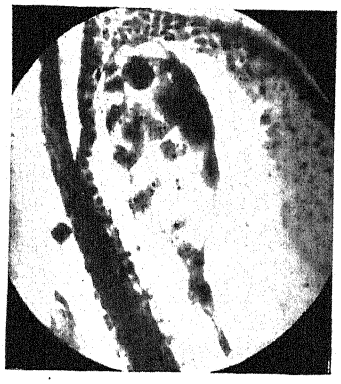
c



d



e



f



g

(*a*) Mature embryo-sac showing a pollen tube that has come up to the level of the egg cell ; a ring of chromatic bodies are seen round egg nucleus ; (*b*) Anaphase of first division of zygote ; (*c*) Simultaneous division of zygote and primary endosperm nucleus ; (*d*) Zygote surrounded by a layer of free-nuclear endosperm ; (*e*) Developing embryo surrounded by a layer of free-nuclear endosperm ; (*f*) Embryo enclosed in free-nuclear endosperm ; (*g*) Embryo with a long suspensor.

In crosses between *S. officinarum* and *S. spontaneum* the seedlings obtained have invariably shown a doubling of chromosomes of the pistillate parent. This might be due to a difference in the relative vitality of the uniting haploid gametes to form viable embryos or to some influence external to itself which cause the death of embryo during development of caryopsis. Perhaps the incompatibility of the haploid '*spontaneum*' genom to exist together with the haploid genom of '*officinarum*' to form a viable zygote might be the cause. How far selective fertilization is responsible for the same or whether successful fertilization is the result of a doubling of chromosomes, is hard to say.

In crosses between the noble cane × *Sorghum*, viable embryos are formed from fertilization of both haploid and diploid eggs in the pistillate parent, whereas in *Saccharum* × *Imperata*, only diploid fertilized eggs were found to be viable, unlike that in *Saccharum* × *Bambusa* hybrids [Janaki Ammal, 1938] where only haploid fertilized eggs have been known to be viable. Hence diploid eggs in the noble cane seem to be favoured at the expense of reduced ones in crosses with other species and genera. Seed development, in general, has been found to be better in interspecific crosses, when the parent containing the high chromosome number is the female [East, 1935; Boyes and Thompson, 1937]. Therefore, any diploid egg in *S. officinarum* in a $2n$ embryo-sac stands a greater chance of being fertilized and producing viable seeds. The haploid fertilized eggs would then be nonviable. For the same reason, diploid pollen grains are less functional in producing triploid progenies.

(*g*) *Consequences of polyploidy*

Doubling of chromosome sets during gametogenesis in *S. spontaneum* is associated with an increase of size of the various parts in the auto-triploids, followed by an increase in its yielding capacity [Janaki Ammal, 1939]. The same chromosome complement has a quantitatively and qualitatively different phenotypic expression when represented different number of times. The triploid mutants of *S. spontaneum* are known to be 'giants'.

Doubling of chromosomes during gametogenesis, leading to non-reduction, is of great importance in the synthesis of new species and widely separated genera. Thus in the trigeneric triple hybridization only those hybrids of *Triticum dicoccum* × *Haynaldia* would cross with *Secale cereale* through functioning of unreduced female gametes [Kostoff and Arutjunova, 1937]. The doubling of chromosomes could be utilized as a means of increasing the crossability between plants and overcoming non-crossability [Karpechenko, 1936]. This fact is of considerable importance in plant breeding as this would serve to bring together a combination of desired characters found in different species and genera. In the words of Karpechenko [1927], 'To learn how to increase arbitrarily the number of polyploid gametes, to learn how to pick out the latter and use them for crossing, is a very alluring task'.

Summary

1. Megasporogenesis in the two species of *Saccharum* have been critically studied. Meiosis in megaspore-mother-cells follows the normal course.

2. Occasionally the innermost megaspore of a tetrad and more commonly the inner haploid dyad cell develop into the embryo-sac.

3. Diploid megaspores are formed by fusion of two inner haploid megaspore nuclei of the spore-tetrad and more commonly observed in *S. officinarum*.

4. Both haploid and diploid embryo-sacs develop and are of the normal eight-nucleate type.

5. Normal and triploid embryos in *S. officinarum* are formed by fertilization of haploid and diploid egg cells.

6. Diploid parthenogenesis and nucellar embryony are recorded in *S. officinarum*.

7. Various abnormalities, like a reversal of the embryo-sac, presence of two egg cells in embryo-sacs, secondary embryo-sacs in the same nucellus, uni-nucleate or binucleate 'antipodal' egg cells, are observed in both the species.

8. Evidences for the origin of triploid mutants and triploid hybrids of *Saccharum* through non-reduction, reunion of daughter-nuclei or splitting of chromosomes in haploid egg cells have been presented.

9. The reunion of two megaspore-nuclei is related as equivalent to a 'sexual fusion' of gametes or 'fertilization' and probably accounts for a non-recurrent parthenogenesis in *Saccharum*.

10. Viability of embryos in *Saccharum* has been found to be probably related to the degree of polyploidy of maternal tissue and endorsperm.

Acknowledgements

For guidance, helpful criticisms and kindly interest throughout the progress of the work, I wish to express my grateful thanks to Dr E. K. Janaki Ammal, M.A., D. Sc., Sugarcane Geneticist, Imperial Sugarcane Breeding Station, Coimbatore. Thanks are also due to Rao Bahadur T. S. Venkatraman, C.I.E., B.A., I.A.S., Government Sugarcane Expert, Imperial Sugarcane Breeding Station, Coimbatore, for kindly providing me with the necessary facilities to work in this Institute.

REFERENCES

Anderson, A. M. (1927). *J. Agric. Res.* **34,** 1001-18

Artschwager, E. ; Brandes, E. W. and Sturrett, R. C. (1929). *J. Agric. Res.* **39,** 1-30

Belling, J. (1926). *Biol. Bull.* **50,** 160-2

Belling, J. and Blakeslee, A. F. (1927). *La Cellule* **37,** 355-65

Bergman, (1935). *Zur Kenntnis der Zytologie der Skandinavischen Antennaria—Arten Hereditas* **20,** 214

Boyes, J. W. and Thompson, W. P. (1937). *J. Gen.* **34,** 203-27

Bremer, G. (1923). *Genetica* **5,** 97-148/273

——— (1929). *Facts About Sugar* **24,** 926-7

Brieger, F. (1928).. *Z. I. A. V.* **47,** 1-53

Cooper, D. C. (1937). *J. Agric. Res.* **55,** 539-51

Coulter, J. M. and Chamberlain, C. J. (1912). *Morphology of Angiosperms* : Appleton & Co., New York

Cheesman, E. E. (1931). *M m. Emp. Market Board*
Chiarugi, A. (1926). *Giorn. Bot. Ital.* (N. S.) **33,** 501-626
Chiarugi, A. and Francini, E. (1930). *Giorn. Bot. Ital.* (N. S.) **37,** 1-250
Chizaki, Y. (1934). *Bot. Mag. Tokyo* **48,** 621-8
Curtis, W. M. (1937). *New Phyto.* **36,** 1, 26-32
Dahlgren, (1928). *Svensk Bot. Tidsk.* **22,** 1-17
Darlington, C. D. (1928). *J. Gen.* **19,** 213-56
——————— (1930). *J. Gen.* **22,** 65-93
——————— (1931). *Biol. Rev.* **6**
——————— (1937). *Recent Advances in Cytology* (2nd Edn.) ; London
Darlington, C. D. and Moffett, A. A. (1930). *J. Gen.* **22,** 129-51
Dutt, N. L. and Rao, K. S. S. (1933). *Ind. J. Agric. Sci.* **3,** 37-56
East, E. M. (1935). *J. Gen.* **21**
Ernst (1914). Quoted from Schnarf (1931)
Ellison, W. (1937). *J. Gen.* **34,** 287-95
Erlanson, E. W. (1929). *Bot. Gaz.* **87**
——————— (1933). *Bot. Gaz.* **94,** 551-66
——————— (1934). *Bot Gaz.* **96,** 197-259
Federley (1931). Quoted by Wilson (1928)
Gaines, E. F. and Aase (1926). *Amer. J. Bot.* **13,** 373-85
Gates, R. R. (1908). *Science* **27,** 193
Gates, R. R. and Rees, E. M. (1921). *Ann. Bot. (Lond.)* **35,** 365-98
Graze, H. (1935). *Jahrb. Wiss. Bot.* **81,** 609-62
Goodspeed, T. H. and Avery, P. (1930). *Cytologia* **1,** 308-27
Gustaffson, A. (1934). *Hereditas* **19,** 259-83
——————— (1935). *Hereditas* **21,** 1-112
Haberlandt. G. (1921). *Sitzb. preuss. Akad. Wiss.* **51,** 861-81 (Quoted by Gustaffson, 1935)
——————— (1923). *Ber. Deuts. Bot. Ges.* **41,** 174-9
Hansen, W. (1920-21). *Exp. Stn. Rec.* **45,** 532
Heilborn, O. (1935). *Acta Hort. Berg.* **11,** 129-84
Hoare, G. V. (1933). *Cellule* **42,** 269-92
Holmgren, I. (1919). *K. Sv. Vet. Akad. Handl.* **59,** (7), 1-118
Humphrey, L. M. (1934). *Cytologica* **5,** 278-99
Janaki Ammal, E. K. (1934). *Cytologia* **5,** 453-9
——————— (1936). *Ind. J. Agric. Sci.* **6,** 1-8
——————— (1937). *Report of the Sugarcane Geneticist for the year* 1937
——————— (1938, 1). *Nature* **141,** 3577
——————— (1938, 2). *Report of the Sugarcane Geneticist for* 1937-38
——————— (1939). *Current Sci.* **8,** 74
Jenkins, T. J. and Thomas, P. T. (1938). *J. Bot. Lond.* **76,** 10-2
Johri, B. M. (1935, 1). *J. Ind. Bot. Soc.* **14,** 49-66
——————— (1935, 2). *Proc. Ind. Acad. Sci.* (B) **1,** 340-8
——————— (1935, 3). *Proc. Ind. Acad. Sci.* (B) **2,** 33-48

Johri, B. M. (1936). *Proc. Ind. Acad. Sci.* (B) **4**, 128-38
Jones, J. W. (1928). *J. Amer. Soc. Agron.* **20**, 774
Jones, H. A. and Emsweller, S. L. (1936). *Hilgardia* **10**, 415
Jorgenson, C. A. (1928). *J Gen.* **19**, 133-211
Karpechenko, G. D. (1927, 1). *Hereditas Lund.* **9**, 349-68
———————— (1927, 2). *Bull. Appl. Bot.* **17**, (3), 305
———————— (1936). *Bull. Appl. Bot.* **11**, 47-50
Katayama, Y. (1935). *Proc. Imp. Ac.* **2**, 110
Kihara, H. and Katayama, Y. (1932). *Kwagaku* **2**, 408
Kihara, H. and Nishiyama (1932-33). *Jap. J. Bot.* **6**
Kiellander, C L. (1935) *Bot. Notiser, Lund.* **87**
Komuro, H. (1922). *Tokyo Bot. Mag.* **36**, 23-4
Kostoff D. and Arutinnova, N. (1937). *Genetica* **19**, 367-9
Krishnaswami, N. and Ayyangar, G. N. R. (1937) *Beih zum Centralb. Bd.* **57**, Abt A. Heft 3, 297-318
La Cour, L. (1937). *Bot. Rev.* **3**, 241
Lammerts, W. E. (1929). *Genetics* **14**, 286
Lawrence, W. J. C. (1936). *Genetica* **18**, 109-15
Ljungdah, H. (1922). *Sv. Bot. Tidsskr.* **18**, 279
Maheshwari, P. (1937). *New Phytol.* **36**, 359
Mangelsdorf, P. C. and Reeves, R. G. (1931). *J. Hered.* **22**, 329-43
Mangelsdorf, P. C. (1935). *J. Hered.* **26**, 128-40
McClintock, B. (1929). *Genetics* **14**, 180
McClung, C. E. (1937). *Handbook of microscopical technique* (2nd Edn.) New York
Messeri, A. (1931). *Nuovo. Giorn. Bot. Ital.* (N. S.) **38**, 409-41
Meurman, O. (1928). *Hereditas Lund.* **11**, 289
Midusima, U. N. and Satto, K. (1937). *Cytologia* **8**, 319
Modilewski, J. (1930). *Ber. Deuts. Bot. Ges.* **48**, 285
———————— (1931). *Bull. Jard. Bot. Kieff* **12**, and **27**
Morinaga, T. and Fukushima, E. (1934). *Jap. J. Bot.* **7**, 73-106
Morinaga, T. (1935). *Jap. J. Bot.* **7**, 207
———————— (1937). *Jap. J. Bot.* **9**, 71
Morris, L. E. and Riccharja, R. H. (1937). *J. Gen.* **34**, 275
Müntzing, A (1928). *Hereditas* **2**, 267
———————— (1930). *Hereditas Lund.* **14**, 153
———————— (1937). *Cytologia (Fuji)* **1**, 211
Namikawa S. and Kawakami, J. (1934). *Proc. Imp. Acad. (Tokyo)* **10**, 668-71
Navashin, M. (1929). *Univ. Calif. Pub. Agric. Sci.* **2**, 377
Newton, W. C. F. (1927). *J. Linn. Soc. (Bot.)* **47**, 339
Newton, W. C. F. and Pellew, C. (1929). *J. Gen.* **20**, 405
Nishiyama, (1929). *Jap. J. Gen.* **5**, 1
———————— (1931). *Jap. J. Gen.* **7**, 49-102
Olmo, H. P. (1937). *Cytologia (Fuji)* **1**, 606
Pace (1913). *Bot. Gaz.* **56**, 376

Percival, J. (1921). *The wheat plant* (a monograph) : London
Poddubnaja-Arnoldi, W. A. (1933). *Planta* **19,** 46
Pope, N. Merrit (1937). *J. Agric. Res.* **54,** 525
Ramanujam, S. (1937). *J. Gen.* **35,** 223
Randolph, L. F. (1932). *Proc. Nat. Acad. Sci.* **18,** 222-9
———— (1936). *J. Agric. Res.* **53,** 881
Rhoades, M. (1936). *J. Gen.* **33,** 355
Rodrigo, Pedro A. (1925). *Philipp. Agric.* **14,** 630
Rosenberg, O. (1927). *Hereditas* **8,** 305
Santos, Jose, K. (1937). *Cytologica* **8,** 220
Sansome, J. W. and Philp, J. (1932). *Recent Advances in Plant Genetics* : London
Schnarf, K. (1931). *Vergleichende Embryologie der Angiospermen* : Berlin
———— (1936). *Bot. Rev.* **2,** 565
Sharp, L. W. (1934). *Introduction to Cytology* (3rd Edn.) New York
Shimotomai, N. (1931). *Bot. Mag. Tokyo* **45,** 356
Skovsted, A. (1934). *J. Gen.* **28,** 407
Suessenguth, K. (1923). *Ber. Deuts. Bot. Ges.* **41,** 16
Teradu, S. (1928). *J. Coll. Agric. Hokkaido, Imp. Univ. Sapporo, (Jap.)* **19,** 245
Thompson (1930). *Genetics* **15**
Tomita (1931). *Sci. Rep. Tohoku Imp. Univ.* (4th series, Biol.) **6**
Watkins, A. E. (1925). *J. Gen.* **15,** 323
———— (1932). *J. Gen.* **25,** 125
Wakauwa (1934-35). *Jap. J. Bot.* **7,** 151
Weatherwax, P. (1926). *Bull. Torrey. Bot. Club.* **53**
———— (1930). *Amer. J. Bot.* **17**
Webber, J. M. (1933). *J. Agric. Res.* **47,** 845
Wilson, E. B. (1928). *The Cell in Development and Heredity.* New York. Macmillan

THE DISTINGUISHING CHARACTERS AND BEHAVIOUR OF SOME GRAPE VINE VARIETIES INTRODUCED AT LYALLPUR IN THE PUNJAB

BY

LAL SINGH, B.Sc. (Hons.), M.Sc. (Calif.)

Fruit Specialist, Punjab, Lyallpur

AND

SHAM SINGH, B.Sc. Agri. (Punjab), Ph.D. (Bristol)

Assistant Horticulturist, Lyallpur

(Received for publication on 29 October 1939)

(With three text-figures)

Introduction

THE grape has almost invariably found a place in the orchards throughout the Punjab, but its cultivation never assumed that commercial importance which is meted out to some other fruits. This may be due chiefly to the cultivation of such varieties as happened to be unsuited to the conditions prevailing and, as such, did not bear crops of that delicious quality for which the fruit from Quetta and Chaman (as known in commerce) has made a name. Obviously the first step to the improvement of this important fruit necessitated the trial of a large number of varieties growing under diverse conditions in various parts of the world to see which of them could be acclimatized profitably and then supplement it by the evolution of new varieties through hybridization. With these aims in view, one hundred and ten varieties were obtained from California, New York, Russia, Australia, Quetta, Peshawar, Nasik and also from some places in the Punjab. The varieties obtained from California include several that are also popular in Palestine and France, those obtained from Russia unfortunately did not survive and those from New York have been planted only recently and it is thus too early to give any authentic information regarding them.

The varieties imported got mixed up somehow, with the result that at the time of fruiting an admixture of several distinct varieties was noticed in rows of most of them. This presented difficulties not only in the matter of recording yields but alsoin actually ascertaining which individualin any particular row to label by the name under which it was originally received. In order to avoid confusion, the different varieties were assigned an identity designation till they were isolated, for which even the standard books on the subject [Bailey, 1922; Hedrick, 1919; 1922; Munson, 1909; Perold, 1927] did not help matters to any appreciable extent, as these works put together do not contain the description of more than a dozen and a half of the varieties reported in this paper. This naturally necessitated the carrying out of detailed investigations into their morphological characters with a view to isolate

them properly and further utilize the data for hybridization work. The importance of the work of this kind is well recognized in the horticulturally advanced countries of the world , where botanical characters of the varieties under cultivation are recorded from time to time and the information, in course of time, forms an asset both to the grower and the investigator.

In India there is a great dearth of literature on the subject particularly with regard to this fruit, which is almost a monopoly of British Baluchistan and Afghanistan at present. In planning the investigational work reported herein, the treatise on viticulture by Perold [1927] was found to be a valuable guide. The technical terms used in describing a vine are, therefore, largely those that are already well recognized in other grape-growing countries of the world.

The investigations reported herein were carried out over a period of five years (1933-37). The mass of descriptive data, collected during this period, has been properly arranged to facilitate easy reference, the arrangement of description being identical for all the varieties. It is hoped that the data, reported in this paper, would be useful in many ways to the research workers, growers and nurserymen. The relative importance of various parts of a vine responsible for giving the varieties their distinguishing characters is discussed and a key to their identification is prepared on that basis. The key thus constructed and reported herein is both easy of adoption and exhaustive inasmuch as it can help to isolate all the varieties in the collection at Lyallpur. Nevertheless the scope of its use may possibly extend to a further lot of varieties in the matter of diagnosing them. Furthermore, the descriptive notes regarding each variety would equip the beginners against undue waste of time and money in the matter of introducing new varieties for trial as the same can be supplied from Lyallpur. This would also help the investigators in their work of breeding new varieties, besides proving of practical importance in the naming of stray varieties, purchasing varieties true to name and detecting the presence of ' rogues '. Much of the confusion regarding correct nomenclature would also be avoided.

Material used

The grape vine varieties, growing in the experimental garden at Lyallpur, that were obtained from California, Australia, Quetta, Peshawar, Nasik, and some places in the Punjab, served as the material for these investigations. The plants were set in their permanent places in the spring of 1928. The soil is sandy loam alluvial. All varieties were trained by three systems of pruning viz. head, cane and cordon, but the descriptions given herein relate to the vines trained on trellis and pruned to ' cane system ' [Bioletti, 1922 ; Pb. Agric. Coll. Mag.; 1935] as all the varieties responded best for cropping to this system.

Methods employed

Study of the following parts of the vine was made in each case on the lines set forth as under :—

(*1*) *General vigour.*—The vigour of the different varieties growing in the collection area was described as ' vigorous ', ' medium ', and ' poor ' according to the general appearance of the plant based on the thickness of trunk and length and thickness of canes.

(2) *Unfolding leaves.*—The colour and pubescence of unfolding leaves was recorded quite early in the growing season for each variety.

(3) *Growing shoots.*—The degree of pubescence on growing shoots was noted early in the growing season, viz. months of April and May. The pubescent shoots are graded as glabrous, cobwebby, downy and felt-like as follows :—

(a) Glabrous.—When the pubescence is almost wanting.

(b) Cobwebby or slightly pubescent.—When the pubescence extends to the first five nodes reckoned from the tip of the shoot.

(c) Downy or fairly pubescent.—When the pubescence extends over the first ten internodes.

(d) Woolly or strongly pubescent.—When the pubescence extends over more than ten internodes.

(4) *Full-grown leaves.*—For a study of the leaf characters only those leaves were selected that were fairly uniform in shape. Such a condition was found to exist in almost all the varieties in case of 9th to 12th leaves counted from the base of the shoot. It may also be noted that the range of occurrence of the leaves of uniform shape was considerably more in case of the vigorously growing varieties. Such observations as leaf shape (Fig. 2), pubescence, dentition, pubescence and colour of leaf nerves, colour and pubescence of petiole, etc. were made separately for each variety. The pubescent leaves are classed as :—

(a) Glabrous.—When the pubescence is almost wanting except a slight amount of it being present on the nerves on the lower surface of lamina.

(b) Downy.—When there is only a fair amount of pubescence which can be rubbed off easily.

(c) Felt-like.—When the pubescence on the lower surface of the leaf is dense giving it a woolly white appearance and withstands rubbing.

(5) *One-year-old wood (canes).*—The properties of the ripened wood were noted after the leaves had dropped in order to see how far they could help in distinguishing varieties. Their study consists of describing the colour, shades and pubescence if persisting. To study the length of internodes ten shoots were taken in case of each variety, which has been described as short, medium-long and long as under :—

Short.—Average length of internodes up to 3·0 cm.

Medium-long.—Average length of internodes from 3·1 to 4·5 cm.

Long.—Average length of internodes over 4·5 cm.

(6) *Flowers.*—The varieties were described as having perfect or imperfect flowers, depending upon the presence or absence of essential parts.

(7) *Bunches and berries.*—Detailed notes on shape, size and compactness of bunches ; size and toughness of peduncle ; size and condition of pedicel ; shape of berries, colour and condition of skin, condition and taste of pulp ; number, colour and shape of seeds, etc., for each variety, were recorded (*Vide* glossary).

PRESENTATION OF RESULTS

(*1*) *Vigour of varieties.*—All the varieties growing in the collection have been placed into three groups, viz. vigorous, medium and poor. It may be mentioned at the outset that the varieties behave differently with respect to this character under diverse conditions but in a collection at any particular place the degree of vigour may give the varieties a distinguishing character. It, therefore, follows that vigour is a feature of relative importance only and its utility is limited to the comparison of varieties growing side by side when conditions are uniform and soil heterogeneity is at its minimum. This character, therefore, has not been employed to classify them.

(*2*) *Unfolding leaves.*—The colour and pubescence of unfolding leaves along with the colour of margins was found to be a useful guide for differentiating varieties, but this was, however, possible only by comparing side by side the growing tips of shoots. This feature provides such a wide range of variation that individuals of no two varieties under study looked alike, but it is to be noted that it is extremely difficult to describe the colour shades and degrees of pubescence, with the result that for diagnostic purposes the descriptive notes regarding this feature were of little use. If, however, coloured diagrams could be made, this character, perhaps, would serve to differentiate varieties better than several other features taken singly.

(*3*) *Growing shoots.*—The growing shoots are either green or have purplish colour in them. The purple colour may either be in streaks or it may be predominating in the region of the growing tips. The degree of pubescence on the two types of canes generally met with varies considerably. The data regarding the classification of varieties under study according to colour and pubescence of green shoots is set out in Appendix I. It would be seen at a glance that comparatively a small number of varieties have purely green coloured shoots, but a large majority of them have purple colour in them. This feature is not so outstanding for the identification of varieties as some others described hereafter. If, however, the data is used in conjunction with other features, the classification of varieties can be greatly facilitated.

(*4*) *Full-grown leaves.*—As stated previously, 9th to 12th leaves on the canes reckoned from the base were employed for noting the shape and pubescence of leaves for all the varieties under trial. Such leaves were invariably found to be of uniform shape and size if growing normally. In Appendix II the varieties have been grouped according to the shape and pubescence of leaves thus studied. With the exception of *Agawam*, the shape of leaves of the remaining varieties is either orbicular or cuneiform (Fig. 2). The varieties having these three forms of leaves are further grouped according to the degree of pubescence on the lower surface of leaves, viz. glabrous, downy, or felt-like. All the varieties under study thus fall into seven groups.

(*5*) *One-year-old wood.*—Notes on the character of one-year-old wood are compiled in Appendix III. This character, when used in conjunction with others, is quite helpful in identifying varieties.

(*6*) *Bunches and berries.*—This, perhaps, provides the best single feature for diagnostic purposes and is also quite easy of accurate description. No two varieties look alike with respect to the character of bunches and berries. The berry characters constituting colour and shape are set out in Appendices

IV and V, respectively. Both of these characters have been found to be very helpful in identifying varieties.

There is always a certain amount of variation in the colour and shape of berries. For instance under ' light purple ' column (Appendix IV) not only the varieties having light purple colour are included but also others that are either red or reddish. Similarly under ' green ' column, varieties having green and yellowish green berries are included ; and under ' light green ' column, varieties having light green, greenish yellow, pale green and yellowish white colour, etc. are included. The shape of berries also varies to some extent in nearly all the varieties, especially in case of those that bear compact bunches. For study of shape, therefore, berries from fairly loose bunches or loose parts of the compact bunches were invariably taken so as to exclude those having abnormal shape from berry shape study.

Notwithstanding all this, certain unsurmountable difficulties were experienced, e.g. in the case of spherical berries there were some slightly deviating from the perfect spherical shape but had to be classed as spherical. The same difficulty was experienced in case of the short-oval and oval-shaped varieties. It is, however, considered advisable to class varieties having short-oval shape as distinct from those having oval shape but also to refer to some other distinguishing characters in cases of dispute.

Description of varieties.—The varieties have been arranged and described in their alphabetical order.

Agawam

Vines.—Of medium vigour.

Shoots.—Medium-thick, medium-long, rough ; colour red in streaks on green ; pubescence strongly woolly ; internodes medium-long ; tendrils medium-long, pubescent, trifid, discontinuous ; tips of growing shoots brownish green ; young leaves appear white due to dense pubescence on both surfaces, margin green.

Canes.—Smoky, angular, bark peeling off.

Leaves.—Dark green on upper but light green on lower surface, thick, rough ; shape cordate ; pubescence downy on upper but felt-like on lower surface ; leaf entire, petiolar sinus slightly open below, others missing ; teeth very broad and pointed ; terminal tooth broad. rounded and pointed ; nerves thick greenish yellow with pinkish dots, strongly pubescent, stalk very thick, yellowish green with pink shades, pubescence downy.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thick and tough ; bunches medium, long, pyramidal, single, loose or compact, even ; pedicel short, thick and warty ; berries medium to large, spherical ; skin purple, thick and leathery ; berry content quite pulpy sweet with a peculiar mango flavour ; seeds dark brown, 2-4 per berry.

A light to medium cropper ; ripens during the month of July.

Angulata

Vines.—Vigorous.

Shoots.—Thick, medium-long, rough ; colour dark purple ; pubescence densely woolly ; internodes medium-long ; tendrils short, pubescent, bi- or

trifid, intermittent ; tips of growing shoots brownish green ; young leaves yellowish green, margin reddish green, pubescence on both surfaces.

Canes.—Smoky on one side and light brown on the other, angular, bark sound.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape cuneiform ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, petiolar and other sinuses well marked ; small and bigger teeth irregularly alternating, medium ; nerves medium-thick, strongly pubescent, yellowish green ; stalk short, thick, strongly pubescent, light green and pink in patches.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thin or medium-thick, soft and brittle ; bunches medium or large-sized, long, irregular, divided, very loose, fairly even ; pedicel long, thick and warty ; berries small or medium-sized, spherical ; skin pinkish yellow, thick and leathery ; berry content juicy, a bit acidic, quality fair, seeds brown, about two per berry.

A light to medium cropper ; ripens in July.

Australian

Vines.—Of medium vigour.

Shoots.—Thin, short, rough ; colour yellowish green with pink lines ; pubescence downy ; internodes medium-long ; tendrils medium-long, bi- or trifid, wooly, discontinuous ; tips of growing shoots reddish green ; young leaves yellowish green, margin red near the tips of teeth.

Canes.—Colour brown on one and greyish yellow on the other side, angular.

Leaves.—Dark green on upper surface but light green on lower one, small, thick and rough ; shape cuneiform ; almost glabrous ; 5-lobed, petiolar sinus open and cup-shaped, basal and lateral sinuses also well marked and V-shaped ; teeth narrow, small ones alternating with bigger ones, terminal tooth very narrow, long and pointed, nerves thin, pinkish, strongly woolly ; stalk short, thick, pink, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, medium-thick, tough ; bunches medium-sized, long, pyramidal, single, fairly compact ; ripening even ; pedicel short, thick and warty ; berries medium-sized, spherical ; skin purple with blue bloom, thick and leathery ; berry content pulpy, firm and sweet ; quality fair ; seed colour reddish brown, 2-4 per berry.

A light cropper ; ripens about the beginning of July.

Bakator

Vines.—Vigorous.

Shoots.—Thick, medium-long, rough ; colour dark purple on upper but green on lower surface ; pubescence densely woolly ; internodes medium-long ; tendrils short, pubescent bi- or trifid, intermittent ; tips of growing shoots brownish green ; young leaves yellowish green, margin reddish green, pubescence on both surfaces.

Canes.—Brown on one and greyish yellow on the other side, angular.

Leaves.—Dark green above but light green on lower surface, thick, rough ; shape cuneiform ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, petiolar and other sinuses well marked, U-shaped ; teeth narrow, long and pointed, and terminal tooth very long and pointed ; nerves medium-thick, strongly pubescent, colour yellowish green ; stalk short, thick, strongly pubescent, colour light green and pink in patches.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thin or medium-thick, soft and brittle ; bunches medium or large-sized, long, irregular shape, divided, loose ; ripening fairly even ; pedicel long, thick and warty ; berries small or medium-sized, spherical ; skin pinkish yellow, thick, leathery ; berry content juicy, a bit acidic, quality fair ; seed colour brown, about two per berry.

A medium cropper ; ripens from the end of June to the third week of July.

Beau Blanc

Vines.—Of poor vigour.

Shoots.—Short, medium-thick, rough ; colour green with red streaks ; pubescence woolly (very small hair) ; internodes short ; tendrils short, bifid, pubescent, intermittent ; tips of growing shoots brownish green ; unfolding leaves greenish yellow, margin pink, pubescent on both surfaces.

Canes.—Smoky, angular, bark sound.

Leaves.—Dark green on upper but light green on lower surface, medium-thick, rough ; shape orbicular ; pubescence downy on lower surface but glabrous above ; 5-lobed, petiolar sinus closed above by basal lobes but open below, basal sinuses less marked than lateral ones ; teeth large, broad and pointed ; terminal tooth narrow, tapering and pointed ; nerves yellowish green having pink or brown shades, pubescent, thin ; stalk short, thin, colour yellowish green with pink shades, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thin, tough ; bunches small or medium-sized, long, pyramidal, single, compact ; ripening even ; pedicel medium-long, thin and warty ; berries small, spherical or short-oval ; skin translucent, yellow or pinkish yellow, medium-thick, cracking ; berry content juicy, mild sweet and of good flavour ; quality fair ; seeds brown, 2 to 3 per berry.

A light cropper ; ripens from the third week of June to the beginning of August.

Bedana

Vines.—Vigorous.

Shoots.—Thick, long, rough ; colour purple on upper but green on lower surface ; pubescence cobwebby ; internodes medium-long ; tendrils long, pubescent, trifid, intermittent ; tips of growing shoots pale green ; young leaves yellowish green, margin of the same colour, pubescent on both surfaces.

Canes.—Smoky angular, bark sound.

Leaves.—Green on upper but light green on lower surface, medium-thick ; shape orbicular glabrous on both surfaces ; 5-lobed, petiolar sinus closed above

but slightly open in the middle, basal and lateral sinuses not well marked, V-shaped ; teeth acute and pointed ; terminal tooth acute and pointed ; nerves thin, light pink but red near their point of origin on the upper surface, slightly pubescent ; stalk short, thin, green with purple streaks, glabrous on both surfaces.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick and brittle ; bunches large-sized, long, pyramidal, single, compact ; ripening fairly even ; pedicel medium-long, thin and warty ; berries small-sized, oval ; skin greenish yellow, medium-thick and cracking ; berry content a bit firm, sweet and of good flavour, seedless.

A medium cropper ; ripens from the middle of June to the middle of July.

Bellino

Vines.—Of medium vigour.

Shoots.—Medium-thick, medium-long and rough ; colour bluish red in patches or lines on green shoots ; pubescence densely woolly ; internodes medium-long ; tendrils short, pubescent, bifid, intermittent ; tips of growing shoots brownish green, woolly, ; unfolding leaves yellowish green, woolly, margins tinted red.

Canes.—Smoky on one side and light brown on the other, round, bark sound.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, petiolar sinus closed above by basal lobes but open below, basal and lateral sinuses well marked, U-shaped ; teeth narrow and pointed, small and big ones irregularly alternating ; terminal tooth long, narrow and pointed ; nerves thin, yellowish green with pink shades, 1st and 2nd laterals red near their point of origin, strongly woolly ; stalk light purple, short, medium-thick, pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thick and tough ; bunches medium-sized, long, pyramidal, single, compact ; ripening even ; pedicel short, thick and warty ; berries medium to large-sized ; shape spherical or short oval ; skin thick, dark purple with blue bloom, leathery ; berry content a bit firm, juicy and sweet ; seeds dark brown 2 to 3 per berry.

A light to medium cropper ; ripens from the middle of June to the middle of July.

Bhokari

Vines.—Very vigorous.

Shoots.—Thick, long, rough ; colour dark purple with green lines or shadss ; pubescence woolly ; internodes long ; tendrils medium, pubescent, bifid, intermittent ; tips of growing shoots brownish green ; young leaves purplish green, margin red, pubescence on both surfaces.

Canes.—Purple, round, pubescence persisting.

Leaves.—Dark green on upper but light green on lower surface, medium-thick and rough ; shape cuneiform ; pubescence glabrous on both surfaces ;

5-lobed, basal sinuses less marked than others ; teeth long, narrow and pointed terminal tooth long, narrow and pointed ; nerves thin, greenish yellow with pink dots ; on upper surface of the lamina the nerves are purple till the point where tertiary nerves arise, but on the lower surface the second lateral nerves are purple only near their point of origin ; stalk short, thin, dark purple with green shades, almost glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, medium-thick, tough ; bunches medium to large-sized, long, pyramidal, usually single, fairly compact, ripening even ; pedicel long, medium-thick, smooth and brittle ; berries large, spherical ; skin greenish yellow, thick and leathery ; berry content juicy, mild sweet, quality fair ; seeds well developed, brownish black, 1-2 per berry.

A heavy cropper ; ripens from the end of June to the end of July.

Black Damascus

Vines.—Vigorous.

Shoots.—Long, thick and rough ; dark purple shades or lines on green ; pubescence strongly woolly ; internodes medium-long ; tendrils medium-long, bifid, pubescent and intermittent ; tips of growing shoots, brownish-green, strongly woolly ; unfolding leaves greenish-white with red margins, dense pubescence on both surfaces.

Canes.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, petiolar sinus closed above but open below, other sinuses well marked ; there is a tooth developed at the base of lateral sinuses ; teeth in two series, small ones regularly alternating with large, broad and pointed ones ; terminal tooth long, narrow and pointed ; leaf nerves strongly pubescent, medium-thick and pinkish yellow in colour but the middle and lateral nerves turn purple at the tips, second lateral nerves purple near their point of origin till the point where the tertiary nerves arise ; leaf stalk green with dark purple shades, short, medium thick and slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thick and tough ; bunches medium or large-sized, short, pyramidal, single and fairly loose ; ripening fairly oven ; pedicel medium-long, thick and warty ; berries medium to large-sized, oval ; skin dark purple with blue bloom, thick and cracking ; berry content a bit firm, melting and sweet ; flavour and quality good ; seeds of brown colour well-developed, 2 to 3 per berry.

A light to medium cropper ; ripens from the beginning to the third week of July.

Black Prince

Vines.—Vigorous.

Shoots.—Long, thick and rough ; colour mostly green with dark purple bands on nodes and streaks on internodes ; pubescence downy ; internodes short ; tendrils medium to long, bi- or trifid, pubescent and intermittent ; tips of growing shoots yellowish green, pubescent ; unfolding leaves, yellowish green with pink margins, pubescence on both surfaces.

Canes.—Smoky on purple back-ground, round.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 3-lobed, petiolar sinus open, but lateral sinuses not very well marked; teeth in two series, small ones regularly alternating with large, broad and pointed ones ; terminal tooth long, narrow and pointed ; leaf nerves medium-thick, pinkish yellow and pubescent ; leaf stalk short, medium-thick, yellowish green with purple shades and pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-thick, medium-long, and tough with or without a lateral bunch ; bunches medium or large-sized, long, pyramidal, single or divided, loose or compact ; ripening even ; pedicel thin, long and warty ; berries large or medium-sized, shape spherical ; skin dark purple with blue bloom, thick and leathery ; berry content separates in a mass from the skin, juicy, sweet and of distinct and good flavour ; very good quality ; seeds well developed, 1 to 3 per berry.

A medium cropper ; ripens from the middle of June to the middle of July.

Black Prince (Calif.)

Vines.—Very vigorous.

Shoots.—Thick, long, rough ; dark purple shades or streaks on green ; pubescence densely woolly ; internodes medium-long ; tendrils long, tri-tetra or pentafid, strongly pubescent, intermittent ; tips of growing shoots brownish green ; young leaves greenish white, margin red.

Canes.—Smoky on purple back-ground, round.

Leaves.—Dark green on upper but light green on lower surface, medium, slightly rough ; shape cuneiform ; pubescence downy on both surfaces ; 5-lobed, petiolar sinus cup-shaped, other sinuses closed above but open below ; teeth either narrow or broad ; terminal tooth long, narrow and broad ; nerves thin, greenish yellow with pink dots on lower surface but purple near their point of origin on upper surface, pubescent ; stalk thick, flattened, dark purple with green streaks ; slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick, tough ; bunches usually large, long, pyramidal, single, fairly compact ; ripening fairly even ; pedicel thick, medium-long and warty ; berries medium or large-sized, spherical ; skin of light purple colour with blue bloom thick and leathery ; berry content firm, melting and sweet, quality good ; seed brownish green, well-developed, 2-4 per berry.

A medium cropper ; ripens from the end of June to the end of July.

Black Hamburg

Vines.—Vigorous.

Shoots.—Medium thick, long, rough ; colour green ; pubescence cob-webby ; internodes short ; tendrils medium-long, slightly pubescent, trifid, intermittent ; tips of growing shoots yellowish green ; unfolding leaves greenish yellow, margin pink, pubescence on both surfaces.

Canes.—Purple, angular.

Leaves.—Dark green on upper surface but light green on lower one, thick and rough ; shape cuneiform ; pubscence downy on upper but felt-like on lower surface ; 5-lobed, petiolar sinus well marked, cup-shaped, others well marked, U-shaped ; teeth large, narrow and pointed ; terminal tooth very narrow, long and pointed ; nerves thick, greenish yellow with pink dots, strongly pubescent ; stalk medium-thick, medium-long, dark purple shades mixed with yellowish green, almost glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, medium-thick, tough ; bunches medium or large-sized, long, pyramidal, single, usually loose ; ripening even ; pedicel thin, long and warty ; berries medium or large-sized, spherical or short oval ; skin purple or dark purple with blue bloom, thick and leathery ; berry content separates in a mass from the skin, more juicy than Black Prince, sweet but flavour not as distinct as in the case of Black Prince ; seed dark-brown, well-developed, 1-2 per berry.

A medium to heavy cropper ; ripens from the 3rd week of June to the end of July.

Buckland's Sweet Water

Vines.—Medium vigour.

Shoots.—Medium-thick, medium-long, rough ; colour mostly green but dark purple lines also ; pubescence downy ; internodes short ; tendrils, pubescent, medium-long, trifid, intermittent ; tips of growing shoots greenish yellow with brown shades ; young leaves greenish yellow, margin pinkish, pubescence on both surfaces.

Canes.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green above but light green below, thick, and rough ; shape orbicular ; glabrous on both surfaces ; 5-lobed ; all sinuses well marked ; teeth broad and pointed ; terminal tooth narrow and pointed ; nerves thin, slightly pubescent, colour greenish yellow with pink dots ; stalk short, thin, slightly pubescent, colour light green with pink shades.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, medium-thick and tough ; bunches medium to large-sized, long, pyramidal, divided, usually loose ; ripening even ; pedicel long, thick, warty ; berries medium to large-sized, short oval or spherical ; skin greenish yellow or pinkish yellow, medium-thin, cracking ; berry content a bit firm, melting and sweet ; quality good ; seed light black, 2-3 per berry.

A medium cropper ; ripens from the middle of June to the middle of July.

Chak 45 G. B.

Vines.—Very vigorous.

Shoots.—Thick, long and rough ; dark purple lines on green ; pubescence woolly ; internodes medium-long ; tendrils short, bi- or trifid, woolly, intermittent ; tips of growing shoots brownish yellow ; unfolding leaves yellowish green, margin pinkish, pubescence on both surfaces.

Canes.—Light brown, angular, thick.

Leaves.—Dark green on upper surface but light green on lower one, medium-thick ; shape orbicular ; almost glabrous on both surfaces ; 5-lobed, petiolar sinus closed above but open below, other sinuses marked, U-shaped ; teeth small or large, narrow ; terminal tooth broad and pointed ; nerves thick, pubescent, greenish yellow with pink shades ; stalk short, thick, slightly pubescent, colour dark purple with creamy yellow shades.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thin and tough ; bunches small, short, loose, single ; ripening even ; pedicel long, thick and warty ; berries large-sized, cylindrical ; skin yellowish green with white bloom, thick and cracking ; berry content pulpy, firm and mild sweet ; seed dark brown, 1-2 per berry.

A light cropper ; ripens about the end of July or the beginning of August.

Chasselas Rose

Vines.—Poor vigour.

Shoots.—Thin, short to medium-long, rough ; greenish yellow ; pubescence downy ; internodes short ; tendrils short, trifid, pubescent, intermittent ; tips of growing shoots brownish green with purple colour at the nodes ; unfolding leaves reddish green, margin red, pubescence woolly on both surfaces.

Canes.—Brown on one side and greyish yellow on the other, round.

Leaves.—Dark green on upper surface but light green on lower one, thick ; shape orbicular ; pubescence downy on lower surface but glabrous on upper one ; 5-lobed, all sinuses well marked, V-shaped ; teeth broad, rounded at the top and pointed ; terminal tooth narrow and pointed ; nerves thin, purple near their point of origin but purplish green above, pubescent ; stalk short, thin, pubescent, colour yellowish green with pink shades.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thin or medium-thick, tough ; bunches small to medium-sized, long, shouldered, pyramidal, single, generally compact ; ripening fairly uniform ; pedicel short, medium-thick and warty ; berries small to medium-sized, spherical ; skin pink or pinkish green, thick, leathery ; berry content slightly pulpy, melting and sweet, flavour good ; seed dark brown, flattened shape, generally two per berry.

A light to medium cropper ; ripens from the middle of June to the 3rd week of July.

Chaouch

Vines.—Very vigorous.

Shoots.—Thick, very long, rough ; colour dark purple ; pubescence strongly woolly ; internodes long ; tendrils long, strongly pubescent, bifid, intermittent ; tips of growing shoots brownish green ; young leaves appear paper white on both surfaces due to strong pubescence, margin deep-red.

Canes.—Purple, round, pubescence persisting.

Leaves.—Green above but appear greenish white on lower surface due to strong pubescence, margin red ; shape cuneiform ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, all sinuses well marked ; teeth either narrow or broad ; terminal tooth long, narrow and pointed, nerves

thick, dark purple near their point of origin but greenish yellow above, strongly woolly ; stalk fairly long, thick, deep purple, strongly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thick, tough ; bunches generally large-sized, long, shouldered, pyramidal, single, compact ; ripening fairly even ; pedicel short, thick and warty ; berries large-sized generally, slightly oval ; skin yellowish green, medium-thick, cracking ; berry content soft, juicy, mild sweet ; seed brownish yellow, well developed, 3 to 4 per berry.

A medium to heavy cropper ; ripens from the middle of June to the beginning of July.

Cornichon

Vines.—Vigorous.

Shoots.—Medium-thick, medium-long and rough ; colour yellowish green with purple shades on the upper surface ; pubescence cobwebby ; internodes medium-long ; tendrils long, trifid, slightly pubescent, intermittent ; tips of growing shoots light green, pubescent ; unfolding leaves yellowish green, margin green, strongly pubescent on upper surface.

Canes.—Smoky on purple back ground, angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; glabrous on both surfaces ; 5-lobed, all sinuses well marked ; teeth mostly narrow and pointed ; leaf nerves thick, pinkish yellow, downy pubescence on both surfaces ; leaf stalk medium-thick, pink shades on green, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, medium-thick and tough ; bunches medium-sized, broad, divided, loose and uneven ; pedicel long, thick and warty ; berries medium-sized, long, ovoid ; skin pink, thick and leathery ; berry content puply, with flat taste ; seeds dark brown, 2-3 per berry.

A very light cropper ; ripens about the end of July.

Cipro Nero

Vines.—Very vigorous.

Shoots.—Thick, long, rough ; colour dark purple having yellowish green streaks or patches ; pubescence downy ; internodes medium-long ; tendrils long, trifid, pubescent, discontinuous ; tips of growing shoots brownish green ; young leaves yellowish green, margin pink, pubescence on both surfaces.

Canes.—Purple, angular.

Leaves.—Dark green on upper but light green on lower surface, thick, rough ; shape cuneiform ; pubescence downy on both surfaces ; 5-lobed, petiolar sinus well marked, cup-shaped, other sinuses also well marked ; teeth broad or very broad, terminal tooth also broad. Nerves creamy yellow with pink shades but purple near their point of origin, second laterals more purple than others, medium-thick, pubescent ; stalk thick, short, purple with green shades, pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thick, tough ; bunches medium or large-sized, long, pyramidal, single, fairly loose ; ripening fairly even but

colour of berries does not change uniformly ; pedicel, medium-long, medium-thick and warty ; berries medium-sized, oval ; skin light purple or purple, thick and cracking ; berry content melting and sweet ; flavour pleasant ; seeds dark brown, 2-3 per berry.

A light cropper ; ripens about the middle of July.

Dakh

Vines.—Very vigorous.

Shoots.—Long, thick and rough ; colour dark purple, pubescence woolly ; internodes medium-long ; tendrils medium-long, strongly woolly, bifid and intermittent ; tips of growing shoots brownish green, densely pubescent, unfolding leaves greenish yellow with red margins, pubescence woolly.

Canes.—Brown on one side and greyish yellow on the other, angular.

Leaves.—Dark green on the upper surface but light green below, thick and rough ; shape orbicular, downy on the upper but felt-like on the lower surface ; 5-lobed, petiolar sinus closed above but open below, lateral sinuses open, U-shaped, basal sinuses slightly open ; teeth narrow, long and pointed, small and large ones irregularly alternating ; terminal tooth very long, narrow and pointed ; leaf nerves densely pubescent, medium-thick, purple on both sides—the intensity of colour decreasing towards the apex ; leaf stalk thin short and dark purple, pubescence downy.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thick and tough ; bunches medium, long, pyramidal, single or divided, compact and even ; pedicel short, thick and warty; berries medium-sized, usually spherical, skin black with blue bloom, thick and leathery ; berry content juicy and fairly acidic ; seeds 2-3 per berry, but sometimes more.

A very heavy bearing variety, good for juice making ; ripens from the third week of June to the third week of July.

Damas Rose

Vines.—Very vigorous.

Shoots.—Medium-thick, long and rough ; bluish-red lines on green ; pubescence cobwebby ; internodes medium-long ; tendrils medium-long, trifid, pubescent, intermittent ; tips of growing shoots reddish green, pubescent ; unfolding leaves yellowish green, margin light pink, dense pubescence on both surfaces.

Canes.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, all sinuses well marked ; teeth in two series, small and large ones irregularly alternating, terminal tooth broad and pointed ; nerves medium-thick, greenish-yellow with light pink shades ; leaf stalk short and thick, colour comprises mixed light purple and yellowish green shades, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-thick, medium-long and fairly tough ; bunches medium or large-sized, pyramidal, single and fairly

compact; ripening fairly even; pedicel medium-long, thick and warty; berries large-sized—larger than all other varieties: shape spherical; skin light rose coloured, medium-thick and cracking; berry content a bit firm, melting juicy and sweet; quality good; seeds 2-5 per berry but not well-developed.

A light to medium cropper; ripens from the middle of July to the first week of August.

Danugue

Vines.—Very vigorous.

Shoots.—Thick, long, rough; colour dark purple in patches or lines on green; pubescence cobwebby; internodes long; tendrils long, trifid, pubescent, intermittent; tips of growing shoots reddish or brownish green; young leaves yellowish green, margin purple, pubescent.

Canes.—Brown on one side and greyish yellow on the other, angular.

Leaves.—Dark purple on upper but light green on under surface, thick; shape cuneiform, almost glabrous on both surfaces, 5-lobed, petiolar sinus cup-shaped and other sinuses open and well-marked; teeth broad and narrow; terminal tooth long, narrow and pointed; nerves thick, yellowish green, slightly pubescent; stalk short, thick, greenish yellow with pink dots, almost glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thick and fairly brittle; bunches medium or large-sized, short or long, pyramidal, single, fairly compact; ripening fairly uneven; pedicel medium-long, medium-thick and warty; berries medium to large-sized, spherical; skin light pink to dark purple, thick and cracking; berry content a bit firm, melting and sweet; seeds dark brown, 2-3 per berry.

A light to medium cropper; ripens in the month of July.

Diamond Jubilee

Vines.—Vigorous.

Shoots.—Medium-long, thick, angular and rough; colour dark purple, pubescence wooly; internodes medium-long; tendrils short, wooly, mostly bifid, intermittent; tips of growing shoots purple with dense pubescence; unfolding leaves light purple offering white shade due to dense pubescence, margin pink.

Canes.—Brown on one side and greyish yellow on the other, angular.

Leaves.—Dark green on upper surface but light green on lower one, thick and rough; shape orbicular; pubescence downy on upper but felt-like on the lower surface; 5-lobed, petiolar sinus closed above due to basal lobes but prominent, other sinuses less marked; teeth in two series—small ones alternating with big, broad, rounded ones; leaf nerves prominent on lower surface, densely pubescent, colour creamy yellow but red near their point of origin upto a length of about half an inch; leaf stalk reddish purple, short, thick and pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thick and brittle; bunches small to medium-sized, short or long, mostly divided, loose and even;

pedicel long, thick and warty ; berries large, short oval or spherical ; skin medium-thick, black with blue bloom, cracking ; berry content firm, pulpy, insipid ; quality poor ; seeds two to three per berry, well developed and of green colour.

A medium cropper ; ripens from the beginning to the end of July.

Dizmar

Vines.—Vigorous.

Shoots.—Thick, long and smooth ; dark purple lines on green ; pubescence downy ; internodes medium-long ; tendrils medium-long, trifid, pubescent, discontinuous ; tips of growing shoots purplish green ; unfolding leaves greenish yellow offering pink shade, margin pink, pubescent on both surfaces.

Canes.—Light brown, angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; leaves glabrous on upper surface but downy on lower one ; 5-lobed, petiolar sinus open, other sinuses also well marked; teeth broad or very broad, terminal tooth narrow ; nerves thin, colour creamy yellow with pink shades, slightly pubescent ; petiole purple with green shades, thin, short, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thin and tough ; bunches medium-sized, long, pyramidal, single, loose ; ripening even ; pedicel medium-long, medium-thick, warty ; berries medium-sized, oval ; skin pinkish or brownish yellow, thick and cracking ; berry content quite firm, pulpy and sweet ; seed brown, 1-2 per berry.

A light cropper ; ripens from the middle of June to the beginning of July.

Doite-de-dessie

Vines.—Of medium vigour.

Shoots.—Thick, medium-long, rough ; colour green ; pubescence cobwebby ; internodes medium-long ; tendrils short, trifid, slightly pubescent, discontinuous ; tips of growing shoots greenish yellow ; unfolding leaves greenish yellow, margin red, pubescent on both surfaces.

Canes.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface thick and rough ; shape cuneiform ; almost glabrous ; 5-lobed, all sinuses well marked ; teeth narrow or broad, long and pointed ; terminal tooth very long, narrow and pointed ; nerves thick, creamy yellow with pink shades, pubescent ; stalk short, thick, yellowish green with pink shades, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, medium-thick, brittle ; bunches medium, short, single or divided, fairly loose, even ; pedicel long thick and warty ; berries medium or large, obovate, skin greenish yellow with white bloom, thick and brittle ; berry content pulpy, firm and sweet, good flavour ; fairly good quality ; seeds small, dark brown, 1-2 per berry.

A very light cropper ; ripens about the end of July.

Fakadi

Vines.—Very vigorous.

Shoots.—thick, long, rough ; dark purple lines on green ; pubescence woolly ; internodes medium-long ; tendrils long, bi- or trifid, pubescent, intermittent ; tips of growing shoots yellowish green ; unfolding leaves yellowish green, margin red, pubescence on both surfaces.

Canes.—Purple, angular.

Leaves.—Dark green above, but light green on the lower surface, thin ; shape orbicular ; pubescence downy on upper surface but glabrous on lower surface ; 3-lobed, petiolar sinus well marked, lateral sinuses less marked ; small teeth regularly alternating with large, broad and pointed ones ; terminal tooth narrow and pointed ; nerves thin, greenish yellow with pink dots, pubescent ; stalk short, thin, light purple with green shades, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick and brittle ; bunches usually large-sized, long, pyramidal, single, very loose ; ripening uniform ; short berries found in almost every bunch ; pedicel long, medium-thick and warty ; berries medium-sized, oval ; skin yellowish green, thick and cracking ; berry content juicy, mild sweet, no flavour ; seed dark brown, small sized, 2-4 per berry.

A heavy cropper ; ripens from the beginning to the end of July.

Foster's Seedling

Vines.—Of poor to medium vigour.

Shoots.—Medium-thick, short to medium-long, rough ; colour mostly green but sometimes dark purple bands on nodes and lines on internodes ; almost glabrous ; internodes medium-long ; tendrils medium-long, bifid, almost glabrous, intermittent ; tips of growing shoots greenish yellow, unfolding leaves pinkish green, margin green, no pubescence.

Canes.—Purple, round.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; almost glabrous on both surfaces ; 3-lobed, petiolar sinus almost closed, lateral sinuses slightly marked ; teeth small or large, broad, rounded ; terminal tooth long and narrow ; nerves medium-thick, pinkish yellow, pubescent on lower surface ; stalk long, thick, slightly pubescent, colour yellowish green with purple shades.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thick, fairly brittle ; bunches medium or large-sized, long, pyramidal, generally single, loose, shot berries in the bunch characteristic of the variety ; ripening fairly even ; pedicel long, medium-thick, warty ; berries medium-sized, spherical ; skin yellowish green, thick, leathery ; berry content firm, slightly pulpy but melting ; very sweet, excellent flavour ; one of the best varieties under trial ; seed dark brown, 2-4 per berry.

A medium to heavy cropper ; ripens from the middle of June to the beginning of July.

Gatak

Vines.—Very vigorous.

Shoots.—Thick, long, rough ; colour bluish red and green mixed in patches ; pubescence cobwebby ; internodes medium-long ; tendrils pubescent, medium-long ; bifid, intermittent ; tips of growing shoots green ; young leaves greenish yellow, margins reddish green but sinuses red tinged, pubescent.

Canes.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface, medium-thick and rough ; shape cuneiform ; almost glabrous on both surfaces ; 5-lobed, petiolar sinus open and well marked but lateral and baisal sinuses not well marked ; teeth large, broad, rounded and pointed ; termnal tooth broad, rounded and pointed ; nerves thin, greenish yellow, slightly pubescent, lateral nerves red near their origin ; stalk short, thick, pink, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thick, fairly brittle ; bunches medium, short, pyramidal, single, fairly loose, even ; pedicel short, thick and warty ; berries medium-sized, spherical with deep depression at stigma-end that changes the shape to irregular ; skin thick, cracking and of pale yellow colour ; berry content a bit firm, melting and sweet, hollow around the seed ; seeds brown, 1-2 per berry.

A very light cropper ; ripens about the middle of July.

Gros Colman

Vines.—Vigorous.

Shoots.—Medium-long, medium-thick and rough ; growing habit erect ; colour purple ; pu escence wooly ; internodes long ; tendrils long, bifid, strongly pubescent and intermittent ; tips of growing shoots light purple to brownish and densely pubescent ; unfolding leaves appearing white due to dense pubescence, margins light green.

Canes.—Smoky on purple back-ground, round.

Leaves.—Dark green on upper but light green looking whitish due to pubescence on lower surface, thick and rough ; shape orbicular ; pubescence on both surfaces, downy above but felt-like below ; 3-lobed or almost entire, petiolar sinus closed above by basal lobes but open below, other sinuses not marked ; teeth slightly narrow, rounded and pointed ; terminal tooth narrow but round and pointed above ; nerves creamy yellow in colour, prominent, thick and strongly pubescent ; second lateral nerves red upto the point from where tertiary nerves arise out of them : leaf stalk short, thick, light purple and pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thin and fairly tough ; bunches small, short, loose and single ; ripening fairly even ; pedicel short, thick and warty ; berries medium to large-sized ; shape spherical ; skin thick, cracking and dark purple changing to bluish black ; berry content firm and sweet ; seeds 3-4 per berry and well developed.

A medium to heavy cropper ; ripens from the third week of July to the 2nd week of August.

Gros Sapat

Vines.—Poor to medium in vigour.

Shoots.—medium-long, medium-thick and rough ; colour brownish yellow ; pubescence cobwebby ; internodes medium-long ; tendrils small, bifid, pubescent and intermittent ; tips of growing shoots yellowish green, slightl pubescent : unfolding leaves greenish yellow, pubescent on both surfaces, margin pink.

Canes.—Smoky on purple back-ground, round.

Leaves.—Dark green on upper but light green on under surface, thin and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surfaces ; 5-lobed, petiolar sinus closed above by basal lobes but open below, basal sinuses less marked than lateral ones ; teeth narrow and pointed, small and big ones irregularly arranged, terminal tooth long, very narrow and pointed ; nerves thin, brownish pale green, strongly pubescent, main and lateral nerves changing red at their tips ; leaf stalk greenish yellow with pink shades, short, medium and pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, medium-thick and tough ; bunches medium to large-sized, long, pyramidal, single, fairly compact ; ripening fairly even ; pedicel long, thin and warty ; berries medium to large-sized, spherical ; skin dark purple changing black, thin and leathery ; berry content separating in a mass from the skin, a bit acidic ; quality fair ; seeds 2-3 per berry.

A medium cropper ; ripens from the middle of June to the middle of July.

Green Large Seeded

Vines.—Vigorous.

Shoots.—Thick, long and rough ; dark purple lines on green ; pubescence cobwebby ; internodes medium-long ; tendrils medium-long, bifid, slightly pubescent, intermittent ; tips of growing shoots brownish green ; unfolding leaves yellowish green, margin pink, slightly pubescent.

Canes.—Light brown, angular.

Leaves.—Dark green on upper surface but light green on lower one, thin and soft ; shape orbicular ; no pubescence on either surface ; 5-lobed ; teeth narrow, small and big ones irregularly alternating ; terminal tooth long, narrow and pointed ; nerves medium-thick, greenish yellow with pink dots, slightly pubescent ; stalk medium-thick, short, colour yellowish green with pink shades, glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short or medium-long, thick and brittle ; bunches medium to large-sized, long, pyramidal, single, fairly compact ; ripening uniform ; pedicel short, thick, warty ; berries large-sized, long oval ; skin yellowish green, medium-thick, cracking ; berry content a bit firm, melting and sweet ; seed colour brown, size well developed, 21-per berry.

A very light cropper ; ripens about the second week of July.

Gujranwala

Vines.—Vigorous.

Shoots.—Long, thick, rough ; colour green ; pubescence wooly ; internodes medium-long ; tendrils medium-long, bifid or trifid, pubescent, intermittent ; tips of growing shoots yellowish green ; unfolding leaves greenish yellow, margin pinkish, pubescence on both surfaces.

Canes.—Purplish, angular.

Leaves.—Light green on upper surface but yellowish green on lower one, thick and rough ; shape orbicular ; glabrous on both surfaces ; 5-lobed, petiolar sinus closed above but open below, basal sinuses less marked, V-shaped, lateral sinuses open, U-shaped ; teeth large, broad, rounded and pointed ; terminal tooth long, narrow and pointed ; leaf nerves thin, slightly pubescent, pinkish yellow ; stalk short, thin, pinkish yellow, almost glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, medium-thick, tough ; bunches small or medium-sized, single, very loose ; ripening uniform ; pedicel long, thick and warty ; berries large-sized, cylindrical ; skin thin, yellow ; berry content slightly pulpy melting and sweet ; flavour not marked ; seed colour light brown, 1-2 per berry.

A very light cropper ; ripens about the middle of June.

Hur

Vines.—Very vigorous.

Shoots. Thick, long and rough ; colour mostly dark purple ; pubescence cobwebby ; internodes medium-long ; tendrils medium-long, bi- or trifid slightly pubescent, intermittent ; tips of growing shoots greenish purple ; young leaves brownish green with deep red margins, slightly pubescent.

Canes. Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface, thin, rough ; shape cuneiform ; pubescence downy on upper but felt-like on lower surface ; 3-lobed, petiolar sinus well marked, open and cup-shaped, lateral sinuses V-shaped, basal sinuses very slightly marked ; teeth irregularly alternating, mostly broad, rounded and pointed, terminal tooth medium or broad and pointed ; nerves thin, greenish yellow, felt-like pubescence on lower surface, lateral nerves purple near their point of origin ; stalk short, thin, dark purple, not pubescent to the unaided eye.

Flowers —Hermaphrodite.

Characters of the bunch.—Peduncle long, thick and tough ; bunches medium or large-sized, long or broad, shouldered, usually single, fairly compact ; ripening even ; pedicel long, thick and warty ; berries medium to large-sized, short oval ; skin thin, cracking, of greenish yellow colour on which reddish brown shades develop ; berry content a bit firm, melting, sweet and of good flavour ; seeds well developed, of brownish yellow colour, 1-2 per berry.

A medium cropper ; ripens about the middle of July.

Hussaini Black Kabuli

Vines.—Very vigorous.

Shoots.—Thick, long and rough ; dark purple streaks on green ; pubescence woolly ; internodes medium-long ; tendrils medium-long, pubescent, bi- or trifid, intermittent ; tips of growing shoots yellowish green, pubescent ; unfolding leaves yellowish green with pink margin, white shade on both surfaces due to dense pubescence, changing purple later.

Canes.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape cuneiform to orbicular ; pubescence downy on upper but felt-like on lower surface ; leaves without lobes but sometimes one or both lateral sinuses develop ; teeth in two series, small ones alternating with bigger ones, narrow or broad but are generally narrow ; leaf nerves medium-thick, pinkish-yellow with green shades and pubescent, second lateral nerves of purple colour on both surfaces upto the point where tertiary nerves arise ; leaf-stalks thick, pubescent and have purple and green shades on them.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thick and tough ; bunches medium-sized usually, long or short, divided, fairly loose and uneven ; pedicel short, thick and warty ; berries large and spherical ; skin black with blue bloom, thick and cracking ; berry content firm, pulpy and sweet ; quality fair ; seed content 2-3 per berry, colour light brown.

A light to medium cropper ; ripens from the end of June to the end of July.

Iona

Vines.—Of poor vigour.

Shoots.—Thin, short and rough ; colour green ; pubescence woolly ; internodes short ; tendrills short, bi- or trifid, pubescent, intermittent ; tips of growing shoots brownish green ; young leaves greenish white, margin green, lower surface pubescent.

Canes.—Smoky angular bark peeling off.

Leaves.—Dark green above but light green on lower surface, thick, rough ; shape cuneiform ; pubescence downy on upper but felt-like on lower surface ; 5-lobed ; petiolar sinus cup-shaped, others V-shaped ; teeth large, rounded and pointed ; terminal tooth narrow and pointed ; nerves thin, colour purplish near their point of origin but brownish or creamy yellow above, densely pubescent ; stalk thin, short, colour purple with yellowish shades, pubescence downy.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, medium-thick, tough ; bunches medium sized, long, pyramidal, single, fairly loose or compact ; ripening even ; pedicel short, medium-thick and warty ; berries medium-sized, spherical ; skin purple, thick and leathery ; berry content a bit pulpy, melting and sweet, mango flavour ; seed dark brown, 2-3 per berry.

A very light cropper ; ripens about the middle of July.

Jaishi

Vines.—Vigorous.

Shoots.—Thick, long and rough ; colour dark purple on upper but green on lower surface ; pubescence woolly ; internodes long ; tendrils very long, bi- or trifid, woolly, intermittent ; tips of growing shoots greenish white, unfolding leaves yellowish green, margins dark-red, woolly.

Canes.—Purple, angular, pubescence persisting.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, petiolar sinus closed above but open below, basal sinuses V-shaped but lateral ones W-shaped ; small teeth regularly alternating with broad, rounded and pointed ones ; nerves thin, pinkish at the base, densely woolly ; leaf stalk short, medium-thick, purplish, densely pubescent.

Flower.—Hermaphrodite.

Characters of the bunch.—Peduncle long, medium-thick and tough ; bunches medium to large-sized, long, shouldered, pyramidal, usually single, generally compact ; ripening fairly even ; pedicel medium-long, thick and warty ; berries medium-sized, oval ; skin greenish yellow on which brown shades develop, thick and cracking ; berry content juicy, a bit acidic ; quality inferior ; seeds of pinkish colour, usually 1-2 per berry.

A light to medium cropper ; ripens from the third week of June to the third week of July.

Kali Sahebi

Vines.—Vigorous.

Shoots.—Medium-thick, medium-long, rough ; dark purple streaks on green ; pubescence cobwebby ; internodes medium-long ; tendrills short, bi- or trifid, slightly pubescent, intermittent ; tips of growing shoots brownish yellow ; young leaves greenish yellow with red margins, slightly pubescent on both surfaces.

Canes.—Purple, angular.

Leaves.—Light green on upper but yellowish green on lower surface, thick, rough ; shape orbicular ; almost glabrous on both surfaces ; 5-lobed, petiolar sinus almost closed other sinuses well marked, U-shaped ; teeth large, broad, rounded and pointed ; terminal tooth long, very narrow and pointed ; nerves medium, creamy yellow with pink dots, slightly pubescent ; stalk short medium-thick, almost glabrous, creamy yellow with purple shades.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, medium-thick, fairly brittle ; bunches medium-sized, long, pyramidal, single, fairly loose ; ripening fairly even ; pedicel long, medium-thick and warty ; berries large-sized, long (1·4 in.) ; shape irregular ; skin light purple, thin, cracking ; berry content firm, pulpy and sweet, flavour lacking ; seed colour brown, 1-2 well developed seeds per berry.

A very light cropper ; ripens in the beginning of August.

Kandhari

Vines.—Very vigorous.

Shoots.—Thick, long and rough ; colour light green ; pubescence cobwebby ; internodes medium-long ; tendrils long, slightly pubescent, bi- or

trifid, intermittent ; tips of growing shoots brownish green ; unfolding leaves yellowish green, pubescent, margins pink.

Canes.—Brown on one side and greyish white on the other, thick and vigorous.

Leaves.—Dark green on upper but light green on lower surface, thick ; shape orbicular ; glabrous on both surfaces ; 5-lobed, basal sinuses less marked than others ; teeth large, broad and pointed ; terminal tooth narrow ; nerves thin, pubescent, yellowish green with pink shades, second laterals pinkish on both surfaces upto the point where the tertiary nerves arise ; stalk short, thick, greenish yellow, glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick and tough ; bunches usually large-sized, loose or compact, pyramidal, single ; ripening fairly even ; pedicel long, thich and warty ; berries big-sized, long-oval ; skin purple, thick and cracking ; berry content sweet ; seeds well developed, 2-3 per berry.

A medium cropper ; ripens from the middle of June to the middle of July.

Kartilaska

Vines.—Very vigorous.

Shoots.—Thick, medium-long and rough ; dark purple lines on green back ground ; pubescence woolly ; internodes medium-long ; tendrils short, trifid, intermittent, strongly pubescent ; tips of growing shoots reddish green, looking white due to strong pubescence ; unfolding leaves reddish green, woolly, margins red.

Canes.—Purple, angular, pubescence persistent.

Leaves.—Dark green on upper but light green on under surface, thick and rough ; shape orbicular ; pubescence downy on both upper and lower surfaces ; 3-lobed, petiolar sinus well marked, U-shaped, lateral sinuses also clear, U-shaped ; teeth broad and pointed, small and big ones irregularly alternating ; nerves medium-thick, strongly pubescent, second lateral nerves red near their point of origin, but greenish yellow with pink shades above ; stalk short, thick and pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-thick and tough ; bunches mediun or large-sized, long, pyramidal, single, fairly compact ; ripening even ; pedicel long, medium thick and warty ; berries medium or large-sized, spherical ; skin greenish yellow with white bloom, thick and cracking ; berry content firm, pulpy, mild sweet with no flavour, seeds of brown colour, 2-3 per berry.

A light to medium cropper ; ripens from the second week of July to the beginning of August.

Khalili

Vines.—Vigorous.

Shoots.—Mostly thin, long, rough ; colour dark purple in patches or streaks on yellowish green ; pubescence downy on both surfaces ; internodes medum-lon g ; tendrills long, bifid, pubescent, intermittent ; tips of growing shoots brownish green, pubescent ; young leaves yellowish green margin pink, pubescent.

Canes.—Smoky on one side and brown on the other, angular, bark peeling off.

Leaves.—Dark green on upper but light green on lower surface, thin, soft; shape cuneiform ; pubescence downy on both surfaces ; 5-lobed, petriolar sinus well marked, basal sinuses less marked than lateral ones ; nerves thin, greenish yellow with pink dots, pubescent ; stalk short, thin, dark purple, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thin, tough ; bunches small or mediun-sized, long, pyramidal, divided, loose, ripening even ; pedicel long, thin and smooth ; berries medium-sized, long-oval ; skin yellowish green with white bloom, thin and cracking ; flesh soft, sweet but flavour not marked ; seed brownish yellow, 1-2 per berry.

A light cropper ; ripens in the beginning of June.

Kharimurat

Vines.—Vigorous.

Shoots.—Thick, medium-long, rough ; dark purple shades on green ; pubescence densely woolly ; internodes medium-long ; tendrils short, bi- or trifid, woolly, intermittent ; tips of growing shoots brownish green ; young unfolding leaves greenish yellow, pubescent on both surfaces, margin greenish yellow.

Canes.—Brown on one side and greyish yellow on the other, angular.

Leaves.—Dark green on upper but light green on lower surface, thick ; shape orbicular ; pubescence downy on lower surface but glabrous above ; 5-lobed, petiolar sinus closed above but open below ; basal sinuses less marked than lateral ones ; teeth narrow ; terminal tooth narrow and pointed ; nerves thin, greenish yellow with pink dots, pubescent ; stalk short, thin, purple coloured with light green shades, pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, medium-thick, tough, bunches medium sized, long, cylindrical, loose ; pedicel long, thick and warty ; berries large-sized, long oval, spherical ; colour green ; berry content firm, pulpy and sweet but no flavour ; seed brownish yellow, 1-2 per berry.

A light cropper ; ripens from the beginning to the end of July.

Kishmish White

Vines.—Vigorous.

Shoots.—Thick, long, rough ; colour bluish red and green in patches : pubescence cobwebby or downy ; internodes medium-long ; tendrils medium-long, pubescent, bifid, intermittent ; tips of growing shoots yellowish green ; young leaves greenish yellow, margin tinted pink ; pubescent slightly.

Canes.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface, thick ; shape cuneiform ; almost glabrous ; 5-lobed, all sinuses equally well marked ; teeth broad, rounded and pointed ; terminal tooth narrow and pointed ; nerves greenish yellow with pink shades, pubescent ; stalk pink, short, thick, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thick and brittle, bunches medium-sized, long, shouldered, pyramidal, single, compact, even; pedicels short, thick and warty; berries medium-sized, oval; skin greenish yellow with brown or pink shades, thin, cracking; berry content juicy, sweet and of good flavour; seeds well developed, brownish yellow, usually one per berry.

A light cropper; ripens about the middle of June.

Luglinga

Vines.—Of poor vigour.

Shoots.—Thin, short, rough; colour green; pubescence downy; internodes medium-long; tendrils short, pubescent, bi- or trifid, intermittent; tips of growing shoots reddish green; young leaves greenish yellow offering pink shades, margin red, slightly pubescent.

Canes.—Smoky, round.

Leaves.—Dark green on upper but light green on lower surface, thick, rough; shape coneiform; pubescence downy on both surfaces; 5-lobed, petiolar sinus very broad and open, basal sinuses slightly marked but lateral ones well marked; teeth large, broad and pointed; terminal tooth long, narrow and pointed; nerves thin, greenish yellow with pink shades, woolly; stalk short, thin, green and brown shades, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thick and tough; bunches small, single, compact, shouldered; ripening even; pedicels short, thick and warty; berries medium-sized, short oval; skin yellowish green with brown shades, medium-thick and cracking; berry content juicy and sweet; berries yellowish brown, 1-3 per berry.

A light cropper; ripens about the middle of June.

Madeleine Angevine

Vines.—Of medium vigour.

Shoots.—Medium-thick, long, rough; colour purple; pubescence woolly; internodes short; tendrils medium-long, bi- or trifid, woolly, intermittent; tips of growing shoots greenish purple changing entirely purple; young leaves yellowish green, margin tinted red, pubescence on both surfaces.

Canes.—Smoky, angular, bark peeling off.

Leaves.—Dark green on upper but light green on lower surface, thick and rough; shape cuneiform; pubescence felt-like on both surfaces; 5-lobed, all sinuses well marked and U-shaped; teeth long, narrow and pointed; terminal tooth long, very narrow and pointed; nerves thin, strongly woolly, colour purplish green but purple near their point of origin; stalk short, thin, dark purple, strongly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, medium-thick, tough; bunches small to medium-sized, short, pyramidal, divided, loose; ripening even; pedical short, thick and warty; berries medium-sized, spherical; skin yellowish green, medium-thick and leathery; berry content soft, melting, juicy; berries translucent; seed brownish yellow to light black, well developed, 2-4 per berry

A light to medium cropper ; ripens about the first week of June and is the earliest ripening variety under trial.

Madresfield Court

Vines.—Very poor vigour.

Shoots.—Thin or medium-thick, very short and rough ; bluish pink shades on green ; pubescence woolly ; internodes short ; tendrils very short, bifid, woolly and intermittent ; tips of growing shoots pinkish green, densely pubescent ; unfolding leaves yellowish white, densely pubescent on both sides.

Canes.—Smoky, angular, pubescence persisting.

Leaves.—Darker green on upper than on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, petiolar sinus closed above by basal lobes but prominently open below, other sinuses less marked and V-shaped ; teeth narrow, long and pointed ; terminal tooth very narrow, long and pointed ; leaf nerves densely pubescent, red near their places of origin and of light green colour having pinkish tinge, leaf stalk short, red and woolly.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thick, tough, without a lateral branch ; bunches small or medium-sized, short, pyramidal, single and compact ; uneven ripening is characteristic of this variety as green, light purple and dark purple berries can be found in every bunch ; pedicel short, thick and warty ; berries light or dark purple, medium or large-sized ; shape oval, berry content firm, melting, very sweet and of excellent flavour ; seeds one to two per berry and of green colour.

A light cropper ; ripens about the third week of July.

Malaga

Vines.—Vigorous.

Shoots.—Thick, long and rough ; dark purple patches or lines on green ; pubescence woolly ; internodes medium-long ; tendrils medium-long, pubescent, bi- or trifid, intermittent ; tips of growing shoots yellowish green with pink dots, pubescent ; unfolding leaves yellowish green, margin pink, pubescent.

Canes.—Light brown, angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, all sinuses well-marked, open, U-shaped ; teeth either broad or narrow, terminal tooth broad and pointed ; nerves medium-thick, creamy yellow with light pink shades, strongly pubescent ; lateral nerves purple coloured near their point of origin ; leaf stalk short, medium-thick, light purple with green shades, pubescent.

Flower.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick and brittle ; bunches medium to large-sized, long, pyramidal, single, fairly compact ; ripening even ; pedicel medium-long, thick and warty ; berries medium-sized, short oval ; skin greenish yellow, thick and cracking ; berry content pulpy, firm and fairly sweet ; seeds well developed, dark-brown coloured, 2-3 per berry.

A light to medium cropper ; ripens from the second week of July to the beginning of August.

Mavron

Vines.—Vigorous.

Shoots.—Long, thick and rough ; dark purple patches or lines on green ; pubescence woolly ; internodes long ; tendrils long, trifid, pubescent, discontinuous ; tips of growing shoots brownish green, young unfolding leaves purplish green, margin green, pubescent.

Canes.—Smoky on one side and light brown on the other, angular, bark peeling off.

Leaves.—Dark green on upper surface but light green on lower one, thin, rough ; shape orbicular ; pubescence downy on lower surface but glabrous on upper one ; 3-lobed, petiolar sinus closed above but open below, basal sinuses non-existent, but lateral ones slightly marked ; teeth large, broad and pointed ; terminal tooth long, narrow and pointed ; nerves thin, creamy yellow with pink shades, lateral nerves dark purple near their point of origin, pubescent ; stalk short, thin, dark purple with green shades, pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, medium-thick and brittle ; bunches medium to large-sized, long, single, pyramidal, fairly loose ; ripening even ; pedicel medium-long, thin and warty ; berries small to medium-sized, short oval ; skin greenish yellow, thick and cracking ; berry content firm, pulpy and sweet ; quality fair ; seed bluish brown, well developed, 2-3 per berry.

A light to medium cropper ; ripens from the middle to the end of July.

Muscat of Alexandria

Vines.—Of medium vigour.

Shoots.—Thick, short, rough, colour green ; pubescence woolly ; internodes medium-long ; tips of growing shoots green ; young leaves appear white due to woolly pubescence, margin reddish ; tendrils long, pubescent, trifid or tetrafid, intermittent.

Canes.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape cuneiform ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, petiolar sinus well marked but basal and lateral sinuses less marked, V-shaped ; teeth large, narrow and pointed ; terminal tooth long, narrow and pointed ; nerves thick, greenish yellow, red near their origin, strongly pubescent on both surfaces ; stalk long, thick, pink, pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, medium-thick, fairly tough ; bunches medium to large-sized, long, pyramidal, divided, loose ; ripening even ; pedicel long, thick and warty ; berries medium to large-sized, short-oval ; skin yellowish green, thick, cracking ; berry content a bit pulpy, melting, very sweet and of distinct muscat flavour ; quality good ; seed brownish green, 1-3 per berry.

A light to medium cropper ; ripens from the beginning to the end of July.

Palomino

Vines.—Vigorous.

Shoots.—Medium-thick, medium-long and rough ; colour dark purple ; pubescence woolly ; internodes medium-long ; tendrils medium-long, trifid, woolly, intermittent ; tips of growing shoots brownish green, pubescent ; unfolding leaves greenish yellow, margin pink, pubescence woolly.

Canes.—Smoky on one side and light brown on the other, angular, bark peeling off.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 5-lobed ; all sinuses open and well marked ; teeth either narrow or broad, small and large teeth irregularly alternating ; terminal tooth long, narrow and pointed ; leaf nerves medium-thick, greenish yellow having pink shades, strongly pubescent, all nerves red near their point of origin on the upper surface of the leaf only ; leaf stalk medium-thick, short, dark purple with green streaks, pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick and brittle ; bunches medium or large-sized, long, pyramidal, divided, very loose ; ripening even ; pedicel long, thick and warty ; berries medium-sized, spherical ; skin yellowish green, thick and cracking ; berry content slightly firm, melting and sweet ; quality good ; seeds of dark brown colour, 2-3 per berry.

A medium to heavy cropper ; ripens from the end of June to the end of July.

Pandhari Sahebi

Vines.—Very vigorous.

Shoots.—Thick, long and rough ; colour green or dark purple shades on green ; pubescence cobwebby ; internodes medium-long ; tendrils long, trifid, pubescent, intermittent ; tips of growing shoots brownish green ; unfolding leaves greenish yellow, margin pink, pubescent.

Canes.—Brown on one side and greyish white on the other, thick and vigorous.

Leaves.—Dark green on upper but light green on lower surface, thick ; shape orbicular ; slightly downy pubescence on upper surface but glabrous on lower one ; 5-lobed, petiolar sinus almost closed, lateral sinuses more marked than basal ones ; teeth large, broad, round and pointed ; terminal tooth broad, dome-shaped and pointed ; nerves thick, colour greenish yellow with pink shades or dots, pubescent ; stalk short, very thick, greenish yellow with pink shades, glabrous.

Flowers.—Practically pistillate.

Characters of the bunch.—Peduncle medium-long or short, thick and tough ; bunches medium or large-sized, appearance attractive due to attractive colour of berries and compactness of bunches, long, pyramidal, single, compact ; ripening uniform ; pedicel long, thick and warty ; berries large-sized, long-oval ; skin yellow—with or without pink shades, thin, cracking ; berry content firm, pulpy, sweet but flavour lacking ; seed dark brown, 1-2 per berry.

A self-sterile variety, but medium to heavy cropper when grown with self fertile varieties ; ripens from the third week of June to the third week of July.

Pay Kani

Vines.—Vigorous.

Shoots.—Long, thick, rough ; dark purple lines on green ; pubescence cobwebby ; internodes long ; tendrils medium-long, bifid, slightly pubescent, intermittent ; tips of growing shoots brownish green ; young leaves greenish yellow, margin pinkish, pubescent.

Canes.—Light brown, angular.

Leaves.—Dark green on upper but light green on lower surface, thick ; shape cuneiform ; glabrous on upper surface but slightly pubescent on lower one ; 5-lobed, petiolar sinus considerably open and conspicuous but basal and lateral sinuses less marked ; teeth broad or narrow, pointed ; nerves thin, greenish yellow, slightly pubescent ; stalk short, thin, light green with pink shades slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, medium-thick and fairly tough ; bunches medium to large-sized, long, pyramidal, divided, ripening uneven ; pedicel long, thick and warty ; berries large, oval ; skin yellowish green, thick and cracking ; berry content pulpy, melting and sweet ; seeds yellowish green with black tints, 1-2 per berry.

A light cropper ; ripens about the middle of July.

Portuguese Blue

Vines.—medium vigour.

Shoots.—Short, medium-thick and rough ; colour greenish yellow ; pubescence woolly ; internodes medium-long ; tendrils medium-long, trifid, pubescent, intermittent ; tips of growing shoots reddish green, pubescent ; unfolding leaves yellowish green, pubescent, margin yellowish green.

Canes.—Smoky on purple back ground, round.

Leaves.—Dark green on upper surface but light green on lower one, thin and slightly rough ; shape orbicular ; pubescence downy on both surfaces ; 5-lobed, petiolar sinus closed above but open below, basal and lateral sinuses open, U-shaped ; teeth narrow and pointed, small regularly alternating with big ones ; terminal tooth broad, round and pointed ; nerves thin, greenish yellow mixed with pink shades, lateral nerves pink near their point of origin ; stalk short, thin, yellowish green with pink shades, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, medium-thick and tough ; bunches small to medium-sized, divided and very loose ; ripening uneven ; pedicel medium-long, thin and warty ; berries small and spherical ; skin thick, leathery, dark purple changing black with blue bloom ; appearance attractive ; flesh juicy, fairly sweet, flavour peculiar ; seed brownish green, 2-4 per berry, well developed.

A light cropper ; ripens from the middle of June to the third week of July.

Prunede Cazoul

Vines.—Vigorous.

Shoots.—Thin to medium-thick, rough ; colour yellowish green ; pubescence cobwebby ; internodes medium-long ; tendrils pubescent, medium-long, trifid, intermittent ; tips of growing shoots light green ; young leaves pinkish green, pubescent.

Canes.—Smoky on one side and light brown on the other, round.

Leaves.—Dark green on upper but light green on lower surface, thick ; shape cuneiform ; almost glabrous ; 5-lobed, petiolar and upper sinuses well marked but basal ones less marked ; teeth long, narrow and pointed ; terminal, tooth very long, narrow and pointed ; nerves thin, yellowish-green, pubescent, second lateral nerves red near their point of origin ; stalk short, thin, pink, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, medium-thick, fairly brittle ; bunches medium or large-sized, short, irregular, single, fairly loose ; ripening uneven ; pedicel medium-long, thick and warty ; berries medium or large-sized, oval ; skin green to dark purple, thick and leathery ; berry content a bit firm, juicy, melting and sweet ; quality fair, seed dark brown, 4-5 per berry.

A medium cropper ; ripens from the middle of July to the beginning of August.

Queen Golden

Vines.—Of medium vigour.

Shoots.—Short, medium-thick and rough ; colour dark purple ; pubescence woolly ; internodes short ; tendrils short, bi- or trifid, pubescent, intermittent ; tips of growing shoots brownish green, densely woolly ; unfolding leaves greenish yellow, woolly with red margins.

Canes.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, petiolar sinus closed above but open below, basal and lateral sinuses well marked, open, U-shaped ; teeth in two series, small ones alternating with large, broad and pointed ones ; nerves thick and strongly pubescent, purple near their point of origin but greenish yellow with pink shades above ; leaf stalk short, thick, dark purple and pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, medium-thick and brittle ; bunches medium or large-sized, long cylindrical or pyramidal, single and compact ; ripening even ; pedicel short, thick and warty ; berries large and spherical ; skin green with white bloom, medium-thick and cracking ; berry content a bit firm, melting, juicy and sweet ; seeds well developed, dark brown coloured, about 4 per berry.

A light to medium cropper ; ripens from the middle of July to the middle of August.

Ribier

Vines.—Very vigorous.

Shoots.—Medium-long, thick and rough ; dark purple patches on green ; pubescence woolly ; internodes medium-long ; tendrils long, pubescent, trifid and intermittent ; tips of growing shoots brownish green, densely pubescent ; unfolding leaves yellowish green with pink margin, strong pubescence on both surfaces.

Canes.—Brown on one side and greyish yellow on the other, angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper but felt-like on lower surface ; 5-lobed, but sometimes the tertiary nerves of second lateral nerves form two more lobes, making a total of seven ; petiolar sinus closed above but open below, other sinuses also marked ; teeth in two series, small ones alternate with big ones that are usually narrow, long and pointed ; terminal tooth long, narrow and pointed ; leaf nerves pubescent, thick and purple near their point of origin but creamy yellow mostly ; leaf stalk short, thick, flattened, pubescent, light purple with yellowish green shades.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thick and tough ; bunches large, long, pyramidal, single, loose and even ; pedicel medium-long, thick and warty, berries large and spherical ; skin jet-black with blue bloom, thick and cracking ; berry content firm, pulpy and sweet ; quality fairly good ; seeds 2-3 per berry and of dark brown colour.

A medium to heavy cropper ; ripens from the beginning to the end of July.

Rish Baba

Vines.—Very vigorous.

Shoots.—Thick, long, rough ; colour dark purple and green mixed ; pubescence cobwebby slightly ; internodes medium-long ; tendrils long, bifid, slightly pubescent, intermittent ; tips of growing shoots brownish or reddish green ; young leaves greenish yellow with pink shades, margin pinkish, pubescent on both surfaces.

Cane.—Light brown but slightly smoky on one side, prominently angular.

Leaves.—Dark green on upper but light green on lower surface, medium-thick ; shape cuneiform ; glabrous on both sides ; 5-lobed, petiolar sinus cup-shaped, other sinuses open and well marked ; teeth reddish green ; broad and pointed ; terminal tooth long, narrow and pointed ; nerves thick, yellowish green with pink shades, pubescent ; stalk short, thick, light purple with green shades, almost glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thin or medium-thick, brittle ; bunches medium or large, long, pyramidal, single, loose, even ; pedicel long or very long, medium-thick, warty ; berries large, long, long-oval ; skin greenish yellow with brown shades, thin or medium-thick, cracking ; berry content a bit firm, melting and sweet ; quality good ; seeds well developed, yellowish pink, 1-3 per berry.

A light cropper ; ripens during the month of July.

Rose

Vines.—Vigorous.

Shoots.—Medium-thick, long and rough ; colour red in lines on green ; pubescence cobwebby ; internodes long ; tendrils long, trifid, pubescent, intermittent ; tips of growing shoots yellowish green ; young leaves greenish yellow giving pinkish tinge, slightly pubescent on both surfaces, margin green.

Canes.—Purple, angular.

Leaves.—Dark green on upper but light green on lower surface ; fairly thick ; shape cuneiform ; almost glabrous on both surfaces ; 5-lobed, petiolar sinus open and cup-shaped, basal and lateral ones less-marked and V-shaped ; teeth broad and pointed ; terminal tooth large, broad and pointed ; nerves greenish yellow, slightly pubescent ; stalk short, thick, slightly pubescent, colour pink and yellowish-green in patches.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick, tough ; bunches medium or large-sized, long, pyramidal, shouldered, divided, fairly compact ; ripening fairly uneven ; pedicel thick, long and warty ; berries medium to large-sized, oval ; skin medium-thick, colour red or light red (attractive), cracking ; berry content slightly pulpy, melting and sweet, flavour good ; seed dark brown, 1-2 per berry.

A very light cropper ; ripens about the middle of July.

Servan

Vines.—Very vigorous.

Shoots.—Medium-thick, long and smooth ; colour green ; pubescence woolly ; internodes medium-long ; tendrils long, pubescent, bi- or trifid, intermittent ; tips of growing shoots yellowish green, pubescent ; unfolding leaves greenish yellow, densely pubescent, margin green.

Canes.—Brown on one side and greyish-yellow on the other, angular.

Leaves.—Dark green on upper but light green on lower surface, medium-thick and rough ; shape orbicular ; pubescence on both surfaces ; 5-lobed, petiolar sinus nearly closed, basal and lateral sinuses open, U-shaped ; small teeth irregularly alternating with large, broad and pointed ones, terminal tooth long, narrow and pointed ; nerves thin, pinkish green, pubescent ; stalk short, thin, yellowish green, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thick and tough ; bunches medium or large-sized, long, pyramidal, fairly loose ; ripening uniform ; pedicel medium-long, thick and warty ; berries medium to large-sized, spherical ; skin light green, medium-thick and cracking ; seeds of dark-brown colour, 3-4 per berry.

A light to medium cropper ; ripens from the second week of July to the beginning of August.

Spin Savai

Vines.—Vigorous.

Shoots.—Thick, long and smooth ; colour mostly green but dark purple shades on green also ; pubescence cobwebby ; internodes long ; tendrils long,

trifid, slightly pubescent, intermittent ; tips of growing shoots light green ; young leaves yellowish green, margin pink, pubescence on both surfaces.

Canes.—Brown on one side and greyish yellow on the other, angular.

Leaves.—Dark green above but light green on lower surface, medium-thick ; shape orbicular ; both surfaces glabrous ; 5-lobed ; petiolar sinus well marked, lateral sinuses more marked than basal sinuses, and teeth-like structures develop at the base of lateral sinuses ; teeth large, broad and pointed ; terminal tooth long, narrow and pointed ; nerves thin, pubescence downy, colour dirty green or light green with pink dots.

Flowers.—Hermaphrodite.

Characters of the bunch.—Pedicels long, medium-thick and warty ; berries long-oval, large-sized ; skin greenish yellow, thin like that of 'bedana' variety, cracking ; berry content firm, melting and sweet, quality good ; seed content *nil* or 1-2 per berry, colour greenish yellow.

A very light cropper ; ripens about the beginning of July.

Sultana

Vines.—Vigorous.

Shoots.—Thick, long and smooth ; colour green ; pubescence downy ; internodes medium-long ; tendrils long, pubescent, bifid, intermittent ; tips of growing shoots yellowish green ; unfolding leaves greenish yellow, margin light pink, pubescent on both surfaces.

Canes.—Smoky, angular.

Leaves.—Dark green on upper but light green on lower surface, medium-thick ; shape orbicular ; both surfaces glabrous ; 5-lobed, petiolar sinus closed, other sinuses well marked, U-shaped ; teeth mostly broad ; terminal tooth long, narrow and pointed ; nerves thick, pubescence downy, colour greenish yellow with light pink shades and reddish near their point of origin on upper surface only ; stalk thick, short, greenish yellow with pink shades, almost glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick, brittle ; bunches large-sized, long, pyramidal, single, compact ; ripening fairly even ; pedicel medium long, thin, warty ; berries small, oval ; skin golden yellow, medium-thick, cracking ; berry content a bit firm, melting, sweet ; quality good ; seedless.

A light to medium cropper ; ripens from the middle of June to the beginning of July.

Sur Savai

Vines.—Vigorous.

Shoots.—Thick, long, smooth ; colour mostly green but sometimes dark purple shades also ; pubescence cobwebby ; internodes long ; tendrils long, trifid, slightly pubescent, intermittent ; tips of growing shoots brownish green ; unfolding leaves yellowish green, margin red, pubescent on both surfaces.

Canes.—Purplish, angular.

Leaves.—Dark green on upper but light green lower surface, medium-thick ; shape orbicular ; glabrous on both surfaces ; 5-lobed, petiolar sinus closed above but open below, other sinuses also marked ; teeth large, broad

and pointed ; terminal tooth long and narrow ; nerves medium-thick, light green with pink dots, pubescence felt-like, second lateral nerves red up to a little beyond the point of origin of tertiary nerves ; stalk short, thick, slightly pubescent, pinkish yellow with green shades.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick, soft and brittle ; bunches medium or large-sized, long, pyramidal, single, loose or compact ; ripening even ; pedicel long, medium-thick and warty ; berries usually large-sized but small (shot) ones also met with in the same bunch, shape long-oval ; skin dark purple having blue bloom, thick, cracking ; berry content slightly firm, melting and sweet ; seeds well developed, usually one per berry and have yellow and blue pigments on them.

A light cropper ; ripens from the end of June to the 3rd week of July.

Tandah

Vines.—Vigorous.

Shoots.—Medium-thick, short, rough ; colour pinkish-green ; pubescence cobwebby ; internodes medium-long ; tendrils short, bifid, slightly pubescent, intermittent ; tips of growing shoots pinkish green ; young leaves greenish yellow, pubescent on both surfaces, margin green.

Canes.—Purple, round.

Leaves.—Dark green on upper but light green on lower surface, smooth and thin ; shape cuneiform ; slight pubescence on both surfaces ; 5-lobed, petiolar sinus well marked, open and cup-shaped, basal and lateral sinuses not marked, V-shaped ; teeth broad, rounded and pointed ; terminal tooth very broad, rounded and pointed ; nerves very thin, yellowish green, slightly pubescent ; stalk short, thin, pink, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick, very tough ; bunches medium-sized, long, pyramidal, single, fairly loose ; ripening even ; pedicel medium-long, thick and warty ; berries medium to large-sized, oval ; skin pinkish or light red, medium-thick, cracking ; berry content juicy and sweet ; quality good, flavour not distinct ; seed yellow, 2-3 per berry.

A light cropper ; ripens about the second week of July.

Tas

Vines.—Vigorous.

Shoots.—Thick, long, smooth ; dark purple lines on green ; pubescence cobwebby ; internodes long ; tendrils short, bifid, slightly pubescent, intermittent ; tips of growing shoots light green ; young unfolding leaves yellowish green, margin red, pubescence on both surfaces.

Canes.—Purple, angular.

Leaves.—Dark green on upper surface but light green on lower one, medium-thick ; shape orbicular ; almost glabrous on both surfaces ; 5-lobed, petiolar sinus open below but closed above, other sinuses well marked ; lateral sinuses W-shaped ; teeth broad and pointed ; terminal tooth long, narrow and pointed ; nerves medium-thick, slightly pubescent, light green with pink dots ; second lateral nerves of dark purple colour upto the point where the tertiary nerves arise ; stalk short, medium thick, greenish purple, slightly pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, thick and tough ; bunches medium to large-sized, long, usually pyramidal, single, fairly compact ; ripening fairly even ; pedicel medium-long, thick, and warty ; berries medium to large-sized, short-oval ; skin greenish yellow, thick and cracking ; berry content firm, pulpy, mild sweet, no flavour ; seeds well developed, dark brown, 2 to 4 per berry.

A light to medium cropper ; ripens about the end of July.

Tor

Vines.—Vigorous.

Shoots.—Thick, long, rough ; colour mostly green ; pubescence downy ; internodes long ; tendrils pubescent, trifid, intermittent ; tips of growing shoots yellowish green ; young leaves yellowish green, margin pink, pubescent on both sides.

Canes.—Brown on one side and greyish yellow on the other, angular.

Leaves.—Dark green on upper but light green on lower surface, medium-thick ; shape cuneiform ; almost glabrous ; 5-lobed, petiolar sinus promi nent, open, cup-shaped but basal and lateral ones, V-shaped ; teeth broad ; terminal tooth long, narrow and pointed ; nerves medium-thick, pinkish green, pubescence felt-like on lower surface ; stalk medium-thick, pinkish, short, almost glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick, tough ; bunches large-sized, long, pyramidal, single, quite compact, ripening even ; pedicel short, thick and warty ; berries large-sized, short-oval or spherical ; skin black with blue bloom, thick and cracking ; berry content firm and sweet ; quality fair ; seeds well developed, light brown with bluish shades, 2-3 per berry.

A light to medium cropper ; ripens about the end of June.

Trentham Black

Vines.—Of medium vigour.

Shoots.—Medium-thick, long, rough ; dark purple shades or lines on green ; pubescence woolly ; internodes medium-long ; tendrils short, pubescent bifid, intermittent ; tips of growing shoots yellowish green ; young leaves pinkish green.

Canes.—Smoky, round.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape cuneiform, pubescence downy on both surfaces ; 5-lobed, petiolar sinus well marked, broad and open, basal sinuses less marked than lateral ones ; nerves medium-thick, yellowish pink and pubescent ; stalk short, thin, greenish yellow with purple shades, almost glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle medium-long, medium-thick, brittle ; bunches small to medium-sized, short or long, pyramidal, single, fairly loose ; ripening even ; pedicel medium-long, medium-thick and warty ; berries medium-sized, short-oval ; skin purple, thick and leathery ; berry content separates in a mass from the skin, melting and sweet ; seed dark-brown, 1 to 2 per berry.

A very light cropper ; ripens about the end of June.

Waltham Cross

Vines.—Very vigorous.

Shoots.—Thick, long, rough ; colour green ; almost glabrous ; internodes medium-long ; tendrils medium to long, bi- or trifid, almost glabrous intermittent ; tips of growing shoots green or brownish green ; young leaves yellowish green ; margin red, almost glabrous.

Canes.—Smoky on one side and light brown on the other, round.

Leaves.—Dark green on upper but light green on lower surface, thick; shape cuneiform ; almost glabrous on both surfaces ; 5-lobed ; petiolar sinus open and cup-shaped, lateral sinuses more marked than basal ones ; teeth large, broad, rounded and pointed ; terminal tooth long, narrow and pointed ; nerves medium-thick, greenish yellow with pink shades, slightly pubescent ; stalk short, medium-thick, yellowish green with pink shades ; almost glabrous.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle long, thick, tough ; bunches medium to large-sized, long, pyramidal, single, loose ; ripening uniform ; pedicel long, medium-thick and warty ; berries large, long-oval ; skin yellowish green with white bloom, thick and cracking ; berry content firm, pulpy and sweet ; quality good ; seeds well developed, brown coloured, 1-2 per berry.

A medium to heavy cropper ; ripens from the end of July to the beginning of August.

Zante Currant

Vines.—Vigorous.

Shoots.—Medium-thick, long and rough ; dark purple streaks on green ; pubescence woolly ; internodes medium-long ; tendrils long, bi- or trifid, densely pubescent and discontinuous ; tips of growing shoots greenish red, densely pubescent, unfolding leaves appear white due to pubescence on both surfaces, margin red, red colour develops after the leaves get slightly bigger.

Canes.—Purplish, angular.

Leaves.—Dark green on upper but light green on lower surface, thick and rough ; shape orbicular ; pubescence downy on upper surface but felt-like on lower one ; 5-lobed, petiolar sinus open and cup-shaped, basal and lateral sinuses less marked and v-shaped ; small and large teeth irregularly alternating and are mostly broad and pointed ; terminal tooth narrow and pointed ; leaf nerves thin and pubescent on both surfaces, lateral nerves dark purple near their places of origin on both surfaces but otherwise are of greenish yellow colour with pink dots ; leaf stalk short, thin, dark purple and densely pubescent.

Flowers.—Hermaphrodite.

Characters of the bunch.—Peduncle short, thin, soft and brittle ; bunches small or very small, long, pyramidal, divided, fairly loose and even ; pedicel long, very thin and smooth ; berries very small and spherical ; skin thin, purple coloured with blue bloom ; berry content juicy, very sweet and of good flavour ; seedless variety.

A light cropper ; ripens from the second week to the end of June.

Discussion of results and construction and use of the identification chart

An accurate and complete study of the character and properties of all the parts of grape vine varieties under trial has been made. Some of the descriptive data so gathered have been tabulated and discussed in the previous section from which it is evident that certain features of the vine are not as good a guide for diagnostic purposes as others, e.g. vigour and growth, which are only of relative importance, are helpful when the varieties are grown side by side in the collection. The other feature, i.e. degrees of colour shades, although an excellent guide to the identification of varieties in the field, yet cannot be usefully employed in describing varieties as degree of colour is very difficult to be recorded with precision. In constructing the identification chart, therefore, only such characters are employed as would be easy of adoption and afford a more or less constant specific value under diverse conditions. These features used in their order of importance are (*a*) leaf shape and pubescence, (*b*) colour of berries, (*c*) shape of berries, (*d*) colour of growing shoots and their pubescence, (*e*) cane characters and (*f*) some characters of peduncle, pedicel and skin (Appendix VI). Referring to the chart (Appendix VI) it is at once clear that all the varieties have only three forms of full-grown leaves, viz. orbicular, cuneiform and cordate (Fig. 2). Each of the three forms (shape) of leaf may have three degrees of pubescence, viz. (*a*) felt-like, (*b*) downy and (*c*) glabrous or no pubescence. It is thus evident that all the varieties can be classified into nine groups according to the shape and pubescence of full-grown leaves but actually all the varieties under trial at Lyallpur have fallen into seven groups. Except in one case, there are numerous varieties in each group, thus necessitating, a further classification according to some other outstanding features. This has been considerably accomplished by using the berry colour feature in conjunction with the leaf shape and pubescence inasmuch as the resultant sub-groups become small enough to be treated separately.

As may be expected, there are differences in colour shades and intensity of colour within the berry colour groups themselves. Besides, such shades are prone to vary slightly with season and locality. Due consideration was given to this aspect of the problem and no definite line of demarcation has thus been drawn between the colour groups as explained under ' Bunches ' and ' Berries ' in the previous section. The varieties falling in the various sub-groups have been further sorted out with the help of (*a*) shape of berry, (*b*) colour and pubescence of growing shoots, (*c*) character of canes and (*d*) some characters of peduncle, pedicel and skin and their importance for identification lies in the order in which they are written. It is evident that all the features enumerated above, when used conjointly in Appendix VI, have helped to isolate all the varieties under trial. It is hoped that this chart would help to isolate a further lot of varieties not reported in this paper.

There is yet another feature of interest afforded by the description of varieties. Although there are not more than a few varieties to select for commercial growing from the list reported in this paper, yet there are many that are outstanding with regard to one or the other most desirable feature. For instance *Madresfield Court, Black Prince* and *Muscat of Alexandria* are

noted for taste and aroma, *Dakh* and *Bhokari* are very prolific, *Pandhari Sahebi* excels every other variety for its attractive bunches and berries, *Damas Rose* is noted for the size of its berries and *Madeleine Angevine, Khalili* and *Kishmish White* are very early varieties. The desirable feature of these and such other varieties may be combined by making crosses between suitable parents, and the most desirable progeny seedlings may be multiplied by vegetative means. This type of work is now under way at Lyallpur as a result of the facilities provided by the Imperial Council of Agricultural Research.

Summary

(1) An accurate and complete study of the character and properties of all the parts of 66 grape vine varieties under trial has been made. It consists of the study of (*a*) vigour, (*b*) unfolding leaves, (*c*) growing shoots, (*d*) full-grown leaves, (*e*) one year-old wood and (*f*) bunches and berries.

(2) Some of the descriptive data so gathered have been tabulated and discussed from which it is evident that certain features of the vine are not as good a guide for diagnostic purposes as others.

(3) In constructing the identification chart, only such characters are employed as would be easy of adoption and afford, more or less, a constant specific value under diverse conditions. These features used in their order of importance are (*a*) leaf shape and pubescence, (*b*) colour of berries, (*c*) shape of berries, (*d*) colour of growing shoots and their pubescence, (*e*) cane characters and (*f*) some characters of peduncle, pedicel and skin.

(4) It is evident that all the features enumerated above, when used conjointly in Appendix VI, have helped to isolate all the varieties under trial.

Acknowledgements

The authors are indebted to various agencies for supplying the plant material, particularly to Professor Frederic T. Bioletti of the University of California who supplied no fewer than 60 varieties free of cost. Thanks are also due to Mr Sangat Singh, research assistant, who partly assisted in collecting, compiling and checking the data reported in this paper.

Mr. Ali Mohd. Qadri, artist, is responsible for the outline drawings of leaves and berries.

Glossary

A number of technical terms used in describing varieties have been explained in the section, ' methods employed ', but there are still others which need clarification to enable the reader to understand their significance fully. The following explanations illustrated by connotations and figures are given to serve the desired purpose.

Tendrils

The tendrils can be simple, bi-furcated or tri-furcated. In some varieties tetra-fid or even penta-fid tendrils are met with. In regard to their position on the cane, they are described as continuous, discontinuous or intermittent.

(*i*) *Continuous.*—When there is a tendril or a bunch opposite every leaf on the cane.

(*ii*) *Discontinuous or intermittent.*—When there is a tendril or a bunch opposite some leaves and no tendril or bunch against others, the arrangement can be termed either discontinuous or intermittent. It is called discontinuous when the discontinuity in the arrangement of tendrils is irregular, but when the discontinuity is regular, the arrangement is termed intermittent.

Leaf shape, nerves, lobes and sinuses, teeth, etc.

(*i*) *Leaf shape, nerves.*—The leaf can be of various forms or shapes depending upon the length of the primary or main nerve in relation to the first lateral nerve and the second lateral nerve (Fig. 1). The shape is also dependent on the angles made by the first lateral nerve with the primary nerve and by the first with the second lateral nerve. The leaves of the varieties described in this paper were either orbicular (round) or cuneiform (wedge-shaped), but in one instance they were cordate (heart-shaped). The forms of leaf may best be understood by referring to Fig. 2.

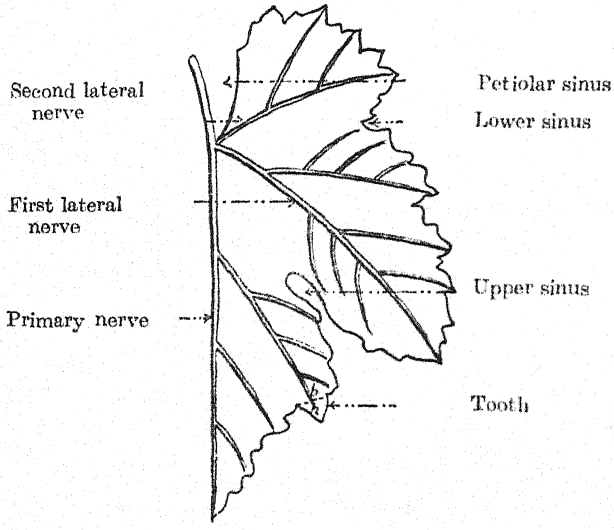


FIG. 1

(*ii*) *Lobing of the leaf and sinuses.*—The leaf can be entire, tri-lobed or five-lobed depending upon the number of sinuses present (Fig. 1). If the value of upper sinus is zero, the leaf is entire. If the upper sinus is clearly marked, the leaf is called five-lobed. In addition to the upper and lower sinuses, there is another sinus called the petiolar sinus, which is formed by the petiolar lobes.

(*iii*) *Teeth.*—The teeth can be of various forms depending upon the value of the ratio expressed by the height (h) of the teeth to its breadth (b) (Fig. 1).

The teeth are very narrow when the ratio is ≥ 1
The teeth are narrow when the ratio is ≥ 0.75
The teeth are broad when the ratio is ≥ 0.50
The teeth are very broad when the ratio is ≥ 0.25

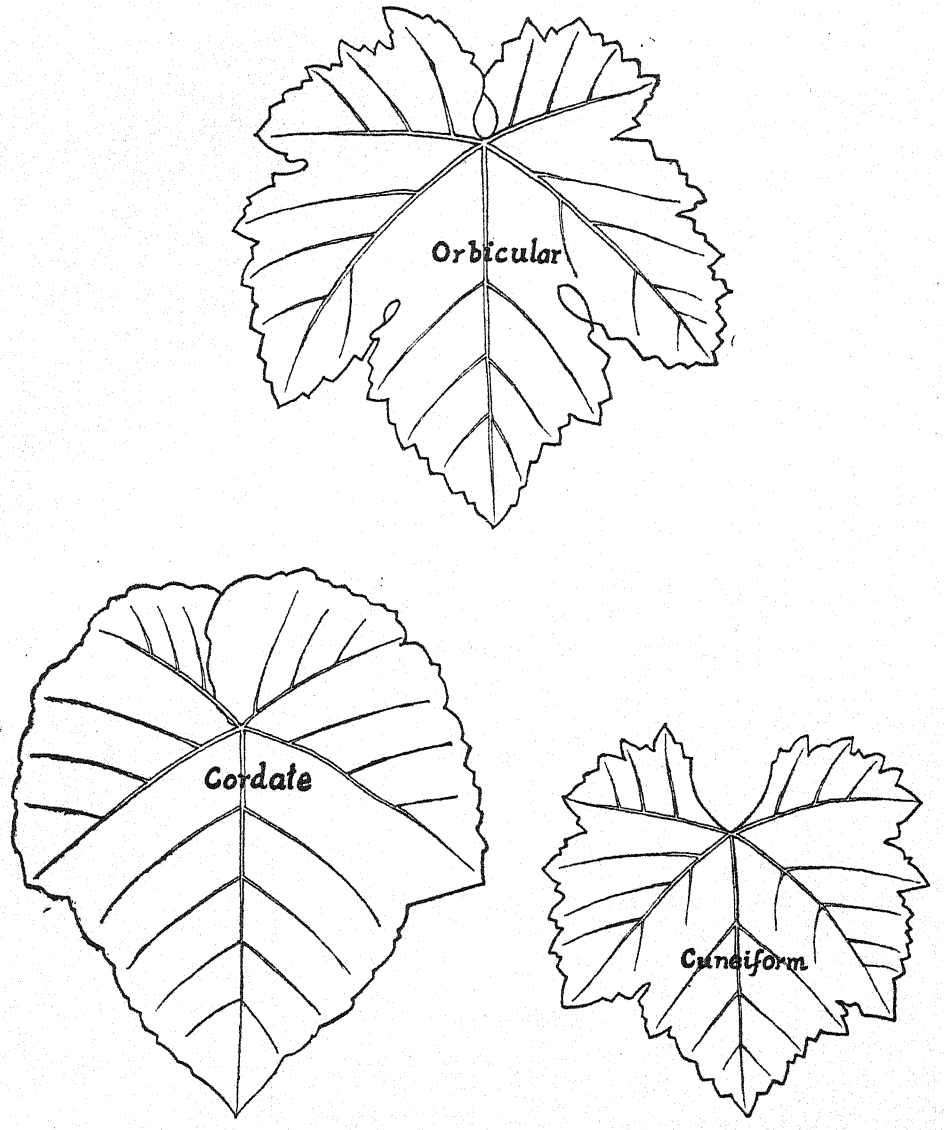


FIG. 2. Different forms of leaf

Description of bunches and berries

The bunch can be small, medium-sized or large-sized.

It is small when the average length diameter is ≤ 10 cm.

It is medium when the average length diameter is ≤ 15 cm.

It is large when the average length diameter is > 15 cms.

The bunch can be long or short depending upon the value of the ratio expressed by its length to its breadth.

It is long when the ratio is > 1

It is short when the ratio is < 1

The bunch is called single, when there is no large stalk division. It is termed divided, when the large stalk division exists.

The bunch is called loose, when the berries can move freely in it. It is termed compact, when the berries are held, more or less, in fixed positions.

The ripening of the bunch is called even, when all the berries in it have ripened, more or less, uniformly. It is termed uneven, when ripe and unripe berries exist in one and the same bunch.

The size of the berry can be small, medium, large or very large depending upon its average diameter.

It is small when the average diameter is $\leq$10 mm.

It is medium when the average diameter is $\leq$15 mm.

It is large when the average diameter is $\leq$20 mm.

It is very large when the average diameter is $>$20 mm.

The shape of the berry can be spherical, short-oval, oval, long oval or irregular, depending upon the ratio of the long diameter to the cross one. To have an idea of the shapes as described in this paper, reference may be made to Fig. 3.

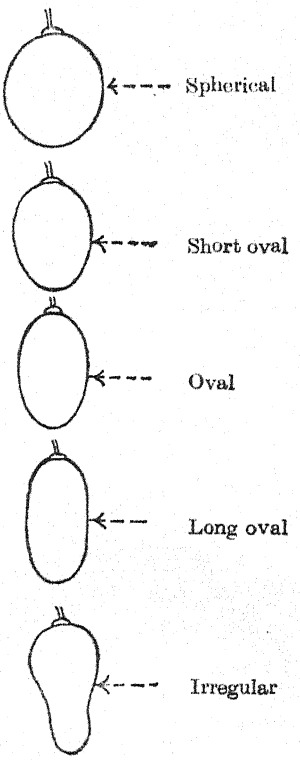


FIG. 3. Different shapes of berry

The skin is termed leathery, when it separates in a mass from the pulp while eating. It is called cracking, when it is crushed along with the pulp while eating.

Cropping propensities

A variety may be light cropper, medium or heavy cropper depending upon the average yield of fruit per vine. The cropping propensities of different varieties have been described on the basis of the average yield taken for the last five years (1933-1937) as follows :—

Very light cropper when the average yield	$\leq$3 lb.
Light cropper when the average yield	$\leq$6 lb.
Light to medium cropper when the average yield	$\leq$12 lb.
Medium cropper when the average yield	$\leq$16 lb.
Medium to heavy cropper when the average yield	$\leq$20 lb.
Heavy cropper when the average yield	$\leq$26 lb.
Very heavy cropper when the average yield	$>$26 lb.

REFERENCES

Bioletti, F. T. (1922). *No. 245 of the University of Calif.*

Bailey, L. H. (1922). *Standard Cyclopedia of Horticulture* : MacMillan Co., New York

Hedrick, U. P. (1919). *Manual of American Grape Growing*: MacMillan Co., New York

——— (1922). *Cyclopedia of Hardy Fruits* : MacMillan Co., New York

Munson, T. V. (1909). *Foundations of American Grape Culture* : Orange Judd Co., New York

Perold, A. I. (1927). *A Treatise on Viticulture* : MacMillan Co., New York

The Punjab Agric. Coll. Mag. (1935). **2**, 181

APPENDIX I

Grouping of grape vine varieties with respect to colour and pubescence of growing shoots

Green (devoid of other shades)				Green having purple shades slightly or predominating			
Woolly	Downy	Cobwebby	Glabrous	Woolly	Downy	Cobwebby	Glabrous
Gujranwala Iona Muscat of Alexandria Portuguese Blue Servan	Chasselas-Rose Luglinga Sultana Tor	Black-Hamburg Doite-de-Dessie Gros Sapat Kandhari. Prunede Cazoul	Waltham Cross	Angulata Agawam Bakator Beau Blanc Bellino Bhokari Black Damascus Black Prince (Calif.) Chak 45 G. B. Chaouch Dakh Diamond Jubilee Fakadi Gros Colman Hussaini Black-Kabuli Jaishi Kartilaska Kharimurat Malaga Madeleine Angevine Madresfield-Court Mayron Palomino Queen Golden Ribier Trentham Black Zante currant	Australian Black Prince Buckland's Sweet Water Cipro Nero Dizmar Kishmish-White Khalili	Bedana Cornichon Damas Rose Danugue Green Large Seeded Gatak Hur Kali Sahebi Pandhari Sahebi Pay Kani Rish Baba Rose Spin Savai Sur Savai Tandah Tas	Foster's Seedling

APPENDIX II

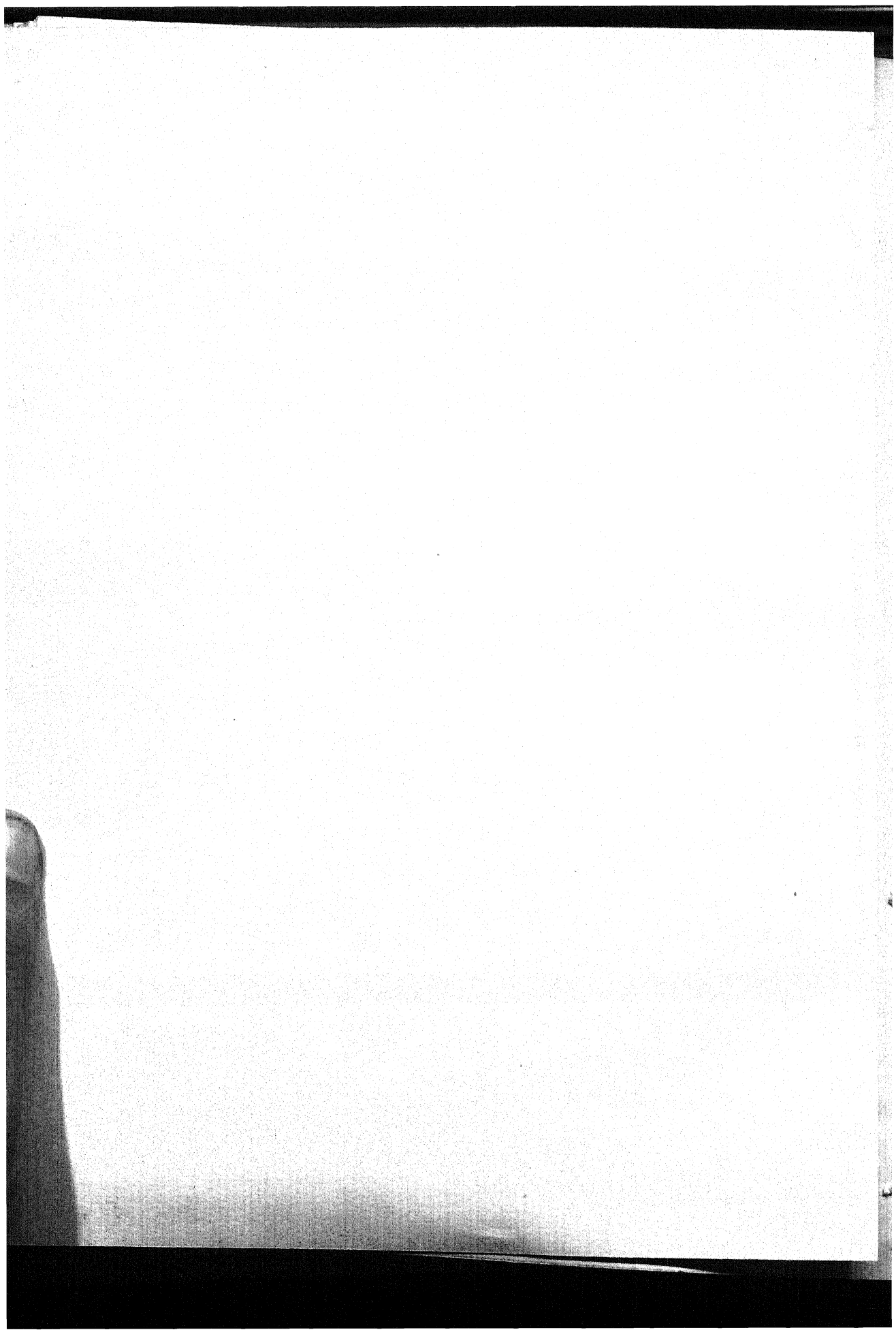
Grouping of grape vine varieties with respect to shape and pubescence of full-grown leaves

Orbicular (round)			Cuneiform (wedge-shaped)			Cordate (heart-shaped)		
Pubescent		Glabrous	Pubescent		Glabrous	Pubescent		Glabrous
Felt-like	Downy		Felt-like	Downy		Felt-like	Downy	
Bellino Black Damascus Black Prince Dakh Damas Rose Diamond Jubilee Gros Colman Gros Sapat Hussaini Black-Kabuli Jaishi Malaga Madresfield-Court Palomino Queen Golden Ribier Servan Zante Currant	Beau Blanc Chasselas-Rose Dizmar Fakadi Kartilaska Kharimurat Mavron Pandhari-Sahebi Purtuguese-Blue	Bedana Buckland's Sweet Water Cornichon Chak 45 G. B. Fosters' Seedling Greend Large eeded Gujranwala Kali Sahebi Kandhari Spin Savai Sultana Sur Savai Tas	Angulata Bakator Black Hamburg Hur Iona Madeleine-Angevine Muscat of Alexandria	Black Prince (Calif.) Cipro Nero Chaouch Khalili Luglinga Tandah Trentham-Black	Australian Bhokari Danugue Doite-de-Dessie Gatak Kishmish-White Pay Kani Prunede-Cazoul Rish Baba Rose Tor Waltham Cross	Agawam	...	...

APPENDIX III

Classifications of grape vine varieties according to the character of canes

Colour of canes smoky			Colour of canes smoky on one side and light brown on the other			Colour of canes smoky on purple background		Colour of canes light brown but slightly smoky on one side	Colour of canes light brown	Colour brown on one side and greyish white on the other	Colour brown on one side and greyish yellow on the other		Colour of canes purplish		Colour of cane purple			
Shape round	Shape angular		Shape round	Shape angular									Shape angular		Shape round		Shape angular	
	Bark peeling off	Bark sound																
		Pubescence absent		Bark sound	Bark peeling off	Shape round	Shape angular	Shape prominently angular	Shape angular	Thick and vigorous	Shape round	Shape angular	Pubescence absent	Pubescence persisting	Pubescence absent	Pubescence persisting	Pubescence absent	Pubescence persisting
		Pubescence persisting																
1	2	3 4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Laglinga, Trentham-Black	Agawam Iona Madeleine-Angevine	Bean Blanc Bedana Sultana	Madresfield-Court	Bellino Pruneda Cazoul Waltham Cross	Angulata	Khalili Mavron Palomino	Black Prince (Calif.) Black Prince Gros Colman Gros Sapat Portuguese-Blue	Cornichon	Black Damascus Buckland's Sweet Water Damas Rose Doite-de-Dessie Gatak Hur Hussaini Black Kabuli Kishmish White Muscat of Alexandria Queen Golden Rish Baba	Chak 45 G. B. Dizmar Green Large-Seeded Malaga Pay Kani	Kandhari Pandhari-Sahebi	Chasselas Rose	Australian Bakator Dakh Danugue Diamond Jubilee Kharimurat Ribier Servan Spin Sava Tor	Gujranwala Sur Savai Zante Currant	...	Foster's Seedling Tandah	Bhokari Chaouch	Black-Hamburg Cipro Nero Fakadi Kali Sahebi Rose Tas	Jaishi Kartilaska



APPENDIX IV

Grouping of grape vine varieties with respect to the colour of berries

Bluish black and black	Dark purple	Light purple and reddish, etc.	Green and yellowish green	Light green (greenish yellow and pale green, etc.)
Bellino	Australian	Agawam	Chak 45 G. B.	Beau Blanc
Dakh	Black Damascus	Angulata	Chaouch	Bedana
Diamond Jubilee	Black Hamburg	Bakator	Fakadi	Bhokari
Hussaini Black Kabuli	Black Prince	Black Prince (Calif.)	Foster's Seedling	Buckland's Sweet Water
Portuguese Blue	Gros Colman	Cornichon	Green Large Seeded	Doite-de-Dessie
Ribier	Gros Sapat	Chasselas Rose	Khalili	Gatak
Tor	Madresfield-Court	Cipro Nero	Kharimurat	Gujranwala
	Prunede Cazoul	Damas Rose	Luglinga.	Hur
	Sur Savai	Danugue	Madeleine Angevine	Jaishi
	Trentham Black	Dizmar	Muscat of Alexandria	Kartilaska
	Zante Currant	Iona	Palomino	Kishmish White
		Kali Sahebi	Pay Kani	Malaga
		Kandhari	Queen Golden	Mavron
		Rose	Waltham Cross	Pandhari-Sahebi
		Tandah		Rish Baba
				Servan
				Spin Savai
				Sultana
				Tas

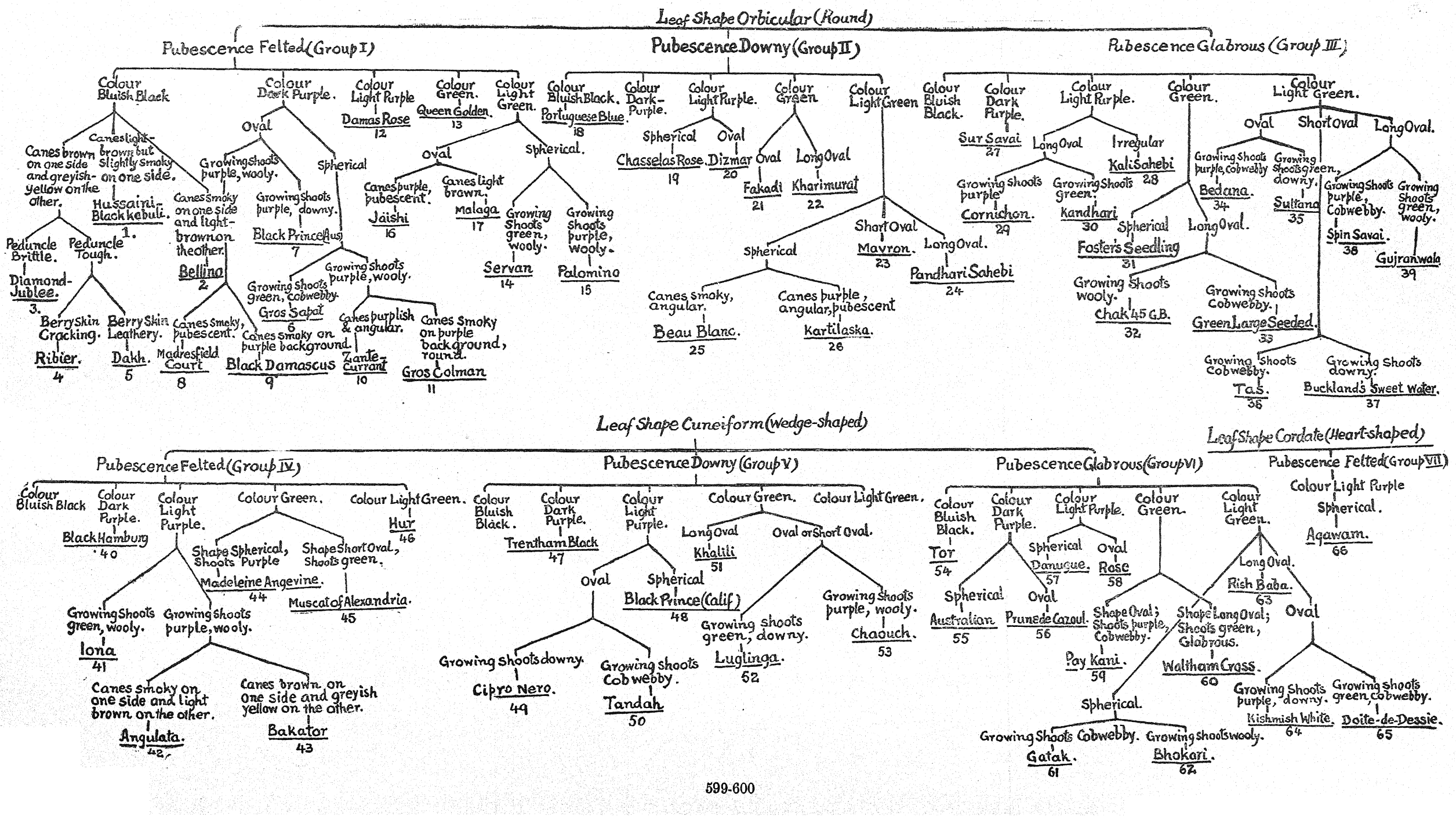
APPENDIX V

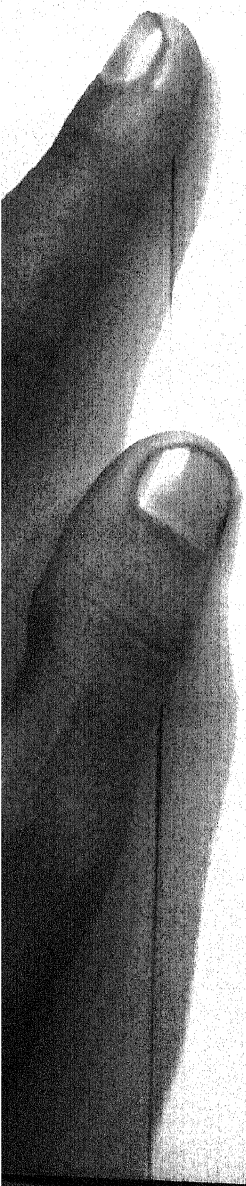
Grouping of grape vine varieties with respect to shape of berries

Spherical	Short oval	Oval	Long oval (Ovoid)	Irregular
Agawam Angulata Australian Bakator Beau Blanc Bellino Bhokari Black Prince (Calif.) Chasselas Rose Dakh Damas Rose Danugue Diamond Jubilee Foster's Seedling Gatak Gros Colman Gros Sapat Hussaini Black Kabuli Iona Kartilaska Madeleine Angevine Palomino Portuguese Blue Queen Golden Ribier Servan Zante Cu rant	Black Hamburg Black Prince Buckland's Sweet Water Hur Luglinga Malaga Mavron Muscat of Alexandria Tas Tor Trentham Black	Bedana Black Damascus Chaoueh Cipro Nero Diznar Doite-de-Dessie Fakadi Jaishi Kishmish White Madresfield-Court Pay Kani Prunede Cazoul Rose Sultana Tandah	Cornichon Chak 45 G. B. Green Large Seeded Gujranwala Kandhari Khalili Kharimurat Pandhari Sahebi Rish Baba Spin Savai Sur Savai Waltham Cross	Kali Sahebi

APPENDIX VI

Showing the Identification of Grape Vine Varieties based on the Shape and Pubescence of Full-grown Leaves, Colour of Berries, Shape of Berries, Colour and Pubescence of Growing Shoots, Cane Characters, and Some Characters of Peduncle, Pedicel and Skin.





A STUDY OF THE PRE-ORCHARD LIFE OF CERTAIN ROOTSTOCKS FOR *CHINEE* ORANGE (*CITRUS SINENSIS* OSBECK) AND ACID LIME (*C. AURANTIFOLIA* (CHRISTM) SWINGLE) AT KODUR

BY

K. C. NAIK, B.Ag. (Bom.), M.Sc. (Bristol)

Superintendent, Fruit Research Station, Kodur

(Received for publication on 15 September 1939)

(With Plates XVII-XXI and one text-figure)

THAT a proper selection of rootstock for the cultivated citrus plays a most important role in the orchard economics and makes all the difference between the success and failure of a plantation are facts established beyond doubt both by observation and scientific findings. Hatton [1932] has summarized the evidence independently brought out by a number of workers to show the differential performance of certain citrus rootstock-scion combinations under diverse environmental conditions. The wide dissimilarity in the matter of rootstock preferences in the different citrus-growing regions has served to accord a considerable practical and economic importance to the rootstock trials in the research programmes relating to the culture of citrus fruits in all parts of the world.

Until very recently seed propagation has been the rule in citrus nursery practices all over South India. During the past few years there has been, however, a distinct trend towards the establishment of budded plantations. At this stage of transition, questions are being very frequently asked on the merits and demerits of the various rootstocks for the superior cultivated varieties of citrus and also of the several hardy, acclimatised or indigenous forms of citrus that are known to abound in this part of India and are reputed to possess a variety of desirable characteristics like tree vigour, resistence to drought and disease, productivity, tolerance to adverse soil and climatic conditions, etc. Information is also being sought on the possible advantages and disadvantages of raising budded plantations instead of the erstwhile system of seedling plantations.

It was, therefore, in the fitness of things that an elaborate rootstock trial for *chinee* orange and a smaller investigation with acid lime scion variety should find a prominent place in the programme of research under the fruit research scheme of the Imperial Council of Agricultural Research at Kodur. The *chinee* orange is the most extensively cultivated variety of sweet oranges in Ceded districts of Madras Province, almost to the exclusion of other

varieties in this region. Similarly, the acid lime occupies a pre-eminent position among the cultivated fruits that fall under the groups of limes and lemons, in this province as also in other parts of India.

From the very nature of these experiments, it is impossible to expect definite results with any degree of finality within a relatively short period of time. With a crop like citrus, a very conservative estimate of the period necessary to determine with some exactitude the longevity of scions on various rootstocks would be not less than 50 years. Pending the availability of results from such long-range experiments, the citrus growers would naturally welcome the release of practical information on the performance of various rootstocks at different stages of the trial. The information collected so far at the Fruit Research Station, Kodur is considered to be of sufficient interest and practical importance to merit immediate dissemination to the citrus-growing public and to the workers in this field elsewhere. Further results of these trials are proposed to be published as and when they become available and seem sufficiently important from the view point of the practical grower and the research worker on citrus.

Materials

One of the experiments which forms the subject of the present paper was designed to test the relative merits of the following varieties of citrus as rootstocks for *chinee* orange.

(1) *Jamberi—C. limonia* Osbeck. :—This is the well-known rough lemon reputed to be popular as rootstock for sweet orange in some parts of Florida, South Africa, Australia and also in the Central Provinces and Bombay Province. It is said to be identical to *Khatti* of the Punjab and North-West-Frontier and is also known as *jamburi* in some parts of India.

(2) *Kichili—C. maderaspatana* Hort. Tanaka. :—This is indigenous to South India, having probably originated as a chance seedling. Tanaka has described it tentatively in his ' Further Revision of Rutaceae Aurantiodiae of India and Ceylon ' [1937], and concludes that the plant is very much like ' sour orange ' (*C. Aurantium*) with leaves broadly winged. It is undoubtedly a very hardy tree and highly productive in Ceded districts (Plate XVII, fig. 1), where it seems to be resistant to a certain extent to drought, neglect, ill-drained soil conditions and also to such diseases as folio-cellosis, dieback, canker, withertip and gummosis.

(3) *Gajanimma—C. pennivesiculata* Tanaka. :—The description of this has also been recently recorded by Tanaka [1937]. According to him it is identical to Bandhuri of Coorg and Attara of the Central Provinces. This too is possibly indigenous to Ceded districts, having also originated as a chance seedling (Plate XVII, fig. 2). It has been found to be susceptible to gummosis, but in other respects possesses all the desirable characteristics of *kichili* though to a lesser degree. It is known to be a more vigorous grower than *kichili*.

(4) *Gabbu-chinee—C. sinensis* Osbeck. Hort. :—This has arisen as a chance seedling in a *chinee* orange plantation (Plate XVII, fig. 3). Excepting for its producing slightly larger, coarse and more warty fruits, it resembles *chinee* orange morphologically.

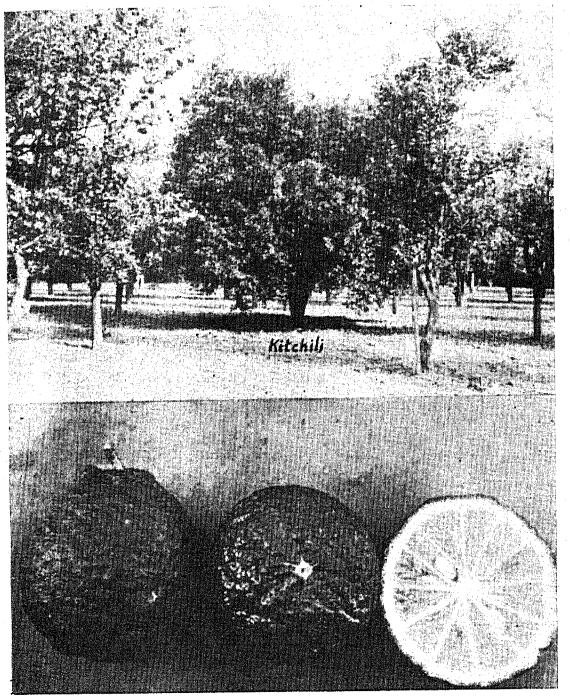


FIG. 1

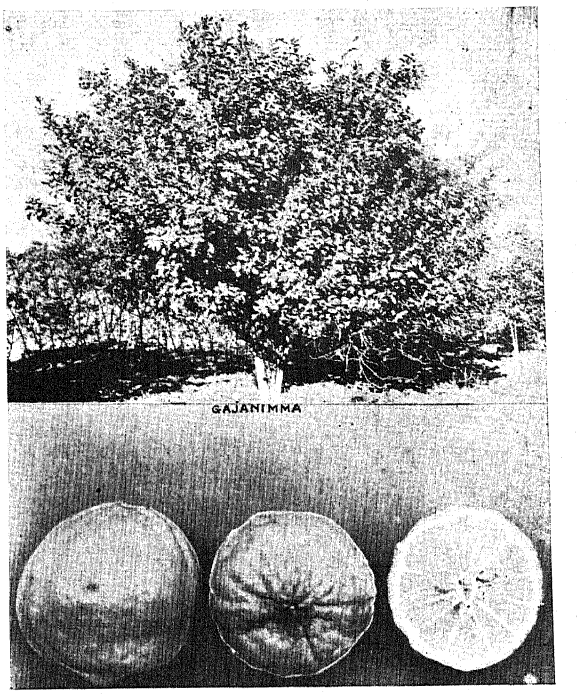


FIG. 2

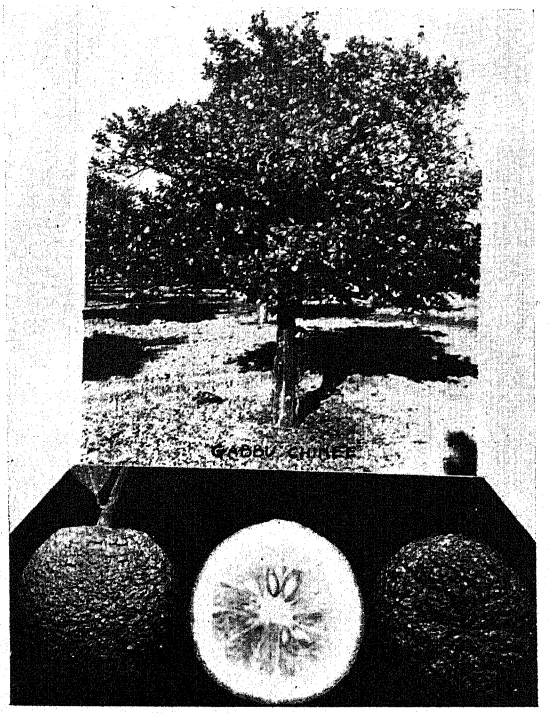


FIG. 3

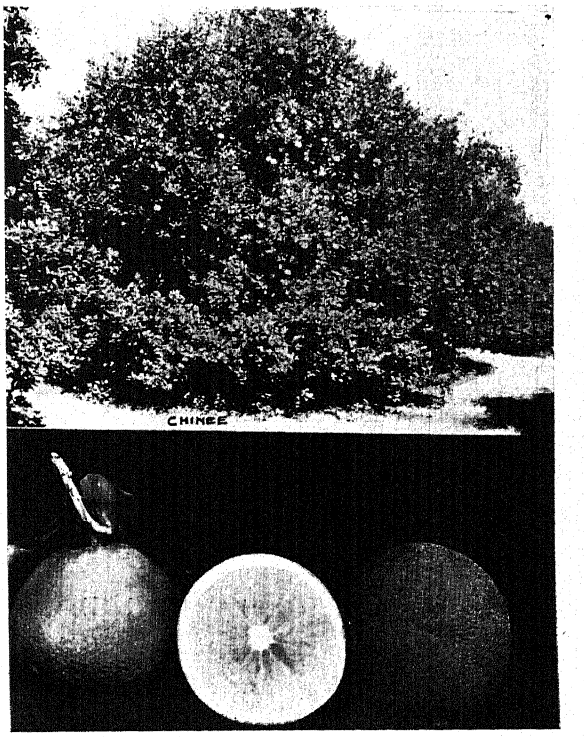


FIG. 4

(5) *Chinee* orange—*C. sinensis* Osbeck. :—It is a variety of sweet oranges (Plate XVII, fig. 4), and does not materially differ from any of the well-known varieties known to trade.

(6) *Billi-kichili—C. Tangerina* Hort. *ex* Tanaka. :—This is identical with the tangerine and closely resembles the Dancy and Beauty of Glen-Retreat varieties introduced to India and cultivated in some parts of the United Provinces. It is known also locally as Hyderabad *kamala* and has been considered to be of some value as a rootstock in parts of Florida.

(7) Pummelo—*C. maxima.* Merr. :—The variety used in the present trials bears round fruits. Its value as a rootstock has been tested at Philippines, Florida and in Hawaii [Pope, 1934].

(8) Acid lime—*C. Aurantifolia* Swingle. :—This is the well-known variety of *kaghzi* lime or *nimbu* so extensively cultivated in all parts of India. El Sawy [1936] and Hodgson [1937] have pointed out that a variety of Egyptian limes has been found suitable as a rootstock in light soils.

(9) *Herale—C. Aurantium* Linn. :—According to Tanaka [1937], this is the true sour orange, also known as Seville orange. The seed parent used in these trials appears to be the true Bitter Seville strain, which is used extensively as a rootstock in California. Its fruits do not develop a sweet and edible pulp as those of *kichili.* Tanaka considers *herale* to be synonymous with *shotang* of Assam, *naradabba* of Madras and *khatta* of the Punjab.

A batch of *chinee* seedlings raised from the same scion parent from which buds were obtained for this experiment were also included in these studies, so that their performance may be evaluated with the *chinee* orange scion on each of the above nine varieties employed as rootstocks.

The scion parent chosen for the experiment is tree No. 10/4 in a private garden close to the station.

For the experiment with acid lime scion, the varieties tried as rootstocks were *kichili, jamberi* and acid lime. As in the case of the other trial, seedlings raised from the acid lime scion parent were also included in this study. The scion parent for this trial was also selected from a private garden in the neighbourhood.

Along with some of the above citrus, a variety popularly known as Vadlapudi orange (syn. country orange or sour country orange or sour orange) has also been included for a study of root-systems of seedlings and of budlings on the seedling rootstocks. It seems from the descriptions that Tanaka [1937] has taken this variety to be synonymous with the *kichili*, although he has not made a specific statement to that effect. The Vadlapudi orange is being extensively cultivated as a table fruit in the Northern Circars and claims an area of about 4,000 acres, while the *kichili* of the Ceded districts is never grown on a commercial scale and exists merely as stray trees in the sweet orange groves. Pending an accurate nomenclature and classification, which is now in progress at Kodur, these two popularly known varieties are treated as distinct from each other in the present paper, although it must be stated that apparently no clear differences seem to exist between the two.

Mokri, C. medica L., is another variety that was originally included for the rootstock trials, but was ultimately discarded for the purpose. The seed-bed and nursery performance of this variety has, however, been reported in these pages.

Methods

The rootstock trials were initiated towards the close of 1935. The seeds of each variety intended for rootstocks as well as of the scion parents for growing as seedling trees were collected from selected individual trees. The scion parents were chosen with care on the basis of their vigour and performance in the two seasons preceding the bud-insertion. As will be shown hereafter, a very much larger number of seedlings than were actually required for bud-insertion and final planting were raised, so as to permit the selection of rootstocks and scion seedlings with the greatest amount of uniformity of growth characters. This procedure was adopted in consonance with the findings of Webber [1931 ; 1932], who has pointed out the possibility of obtaining a progeny, all individuals of which are likely to be genetically identical, by the process of eliminating the variants among the seedlings. It was not, however, possible to sow uniform number of seeds in the case of every variety.

The seeds of all the varieties were sown towards the close of the year 1935 and the seedlings transplanted in nursery beds from June to September 1936. Data on the percentage of germination, the extent of polyembryony as determined by the counting of the actual number of seedlings produced, and also the extent of variability based on the growth measurements were collected at one or more stages of the growth of the plants in seed and nursery beds.

During the first half of January 1937, a number of vigorous growing variants in nursery beds were utilized for a trial to obtain rough indications of rootstock effects upon the *chinee* scion. Detailed ' take ' of buds on each of these variants were suitably recorded along with the extent of variability of these. The budded plants were transplanted to separate nursery beds during July 1937, at which time the girth records were again collected.

At the time of transplantation of seedlings from seed to nursery beds during July to September 1936, 24 seedlings of eight different varieties were selected for a study of root system. These plants were excavated with considerable care, a trench being dug out on either side and the roots traced as far as practicable to their ultimate tips. The root systems were then drawn and described *in situ*, and were finally reconstructed ; and one specimen from each variety was mounted on cardboards and photographed. The descriptions recorded from these studies along with the data collected on the extent of success in transplantation of seedlings have been utilized to obtain an idea of the possible influence exerted by the various root systems on the life of the plants subsequent to the operation of transplantation from seed to nursery beds.

A separate batch of 96 seedlings of eight different citrus varieties were also planted in September 1936 in a separate plot at a distance of six feet from plant to plant and eight feet from row to row for pursuing the study of roots in later stages of growth. Six seedlings of each of these varieties were budded to a selected *chinee* orange tree in January 1937 and the other six were left to grow as unworked seedlings. One budded plant from each variety along with an unworked seedling of the same variety was lifted every year

during the following three years for a comparative study of the root system as stated above.

The actual budding operation of the finally selected seedling rootstocks for the main experiment both with orange and lime scion was done in July 1937 by one operator. The finally selected budded orange and lime plants were planted out in October, 1938.

The plan of layout of the orange rootstock trial as approved by the Statistician of the Imperial Council of Agricultural Research consists of six replications or blocks for ten treatments. Three trees on each of the nine rootstock varieties and three *chinee* orange seedling trees were planted out in each block, the position of the trees within each of the 60 sub-plots and that of the treatments within each of the six blocks having been determined at random. The plants were planted by the quincunx system with a spacing of about 28 feet from tree to tree.

The soil of this plot was analysed by the Government Agricultural Chemist, Coimbatore ; and on the basis of his report it is found that the soil is red sandy loam of great depth with about 25 per cent of finer fractions in surface layers, and more of clay fractions in the lower strata. The *p*H of the soil is almost neutral in reaction, being 7·5. The total water-soluble salts are very low with no difference between the surface and sub-layers. The water-holding capacity and the pore space are also uniformly fair. The area is, therefore, considered to provide ideal plots for this type of experimentation.

In the case of acid lime trial, the plan of layout consists of six replications of four treatments (budlings on three rootstock varieties and acid lime seedlings). The spacing adopted in this case was 20 feet square. The soil analysis of the plot reserved for this trial shows that this plot is identical with that used for the orange rootstock trials.

At the time of planting the trees in both the experiments measurements of trunk thickness of the rootstock stem and scion stem and of the height of the plants were collected and recorded. Once a year such records are proposed to be collected in future so as to trace the differential growth effects under each of the treatments. In the present paper, the data relating to the series of measurements collected in the orchard immediately after planting are only discussed along with those collected prior to the planting.

Data and inferences

1. Chinee *orange rootstock trial*

In Table I are presented the data collected on germination and ployembryony, etc. in seed beds and growth and variability in nursery beds, in the case of various rootstock varieties for *chinee* orange.

Table I shows that wide differences exist between the various varieties particularly with regard to the growth prior to the budding stage. Clear differences are also observed in regard to the phenomenon of ployembryony as determined on seedling counts, and percentage of germination.

TABLE I

Summarized growth record and other observations on seedlings

(*Rootstock trial for* chinee *orange*)

Serial No.	Variety of root-stock	Ger-mina-tion	Time taken for ger-mina-tion in days	Seed-lings from apogamic embryos*	Buddable plants with a diameter of 0·70 cm. or above, at 9" height on 7-11-36	Aver-age height in Nov-ember, 1936	Coeffi-cient of varia-bility	Average diameter at 12 cm. height in Novem-ber, 1936	Coeffi-cient of varia-bility
		Per cent		Per cent *	Per cent	cm.	Per cent	cm.	Per cent
1	2	3	4	5	6	7	8	9	10
1	Sweet orange (*Chinee*)	43·00	20	...	...	38·80	20·00± 0·87	0·33	32·83± 0·01
2	*Kichili*	78·37	15	57·00	6·0	55·80	24·55± 0·25	0·50	21·80± 0·01
3	*Gajanimma*	62·80	19	65·10	59·0	60·80	20·25± 0·84	0·74	25·68± 0·01
4	*Gabbu chince*	80·00	17	4·30	2·0	43·60	26·61± 0·78	0·42	24·88± 0·01
5	*Jamberi*	99·10	20	73·40	53·0	62·00	23·06± 0·95	0·68	27·20± 0·01
6	*Billi-kichili*	85·20	24	16·50	...	34·90	34·41± 0·84	0·34	29·11± 0·01
7	Pummelo	91·00	17	...	12·0	36·80	36·28± 1·44	0·50	28·00± 0·01
8	Acid lime	80·00	20	38·66	3·0	54·60	22·43± 0·83	0·45	26·22± 0·01
9	*Herale*	50·00	(*)	2·05	(*)	(*)	(*)	(*)	(*)
10	*Chinee* (unbudded)	62·00	20	...	...	19·10	16·39± 0·43	0·21	31·43± 0·01
11	*Mokri*	82·00	20	...	31·9	36·10	27·53± 0·98	0·53	35·28± 0·02

NOTE :—Chinee under item No. 1 is from a parent different from that mentioned under item No. 10.

*Calculated on the basis of actual number of seedlings obtained from 100 seeds.

(*) Records not available.

In regard to the growth in the nursery, the data indicate that *jamberi* and *gajanimma* make the most vigorous growth during the first year. It is also seen that height measurements do not afford any uniformly reliable indication of the suitability of the seedlings to receive buds.

The data relating to seedlings from two different parents of *chinee* appear to disclose the fact that the rate of growth is a factor which is largely influenced by the individual parent in this variety.

The data collected on percentage 'take' of buds on vigorous growing variants and also on the variability among these seedlings are presented in Table II.

TABLE II

Data on percentage 'take' and growth of seedling variants as well as on variability among such seedlings at the time of budding

(*Rootstock trial for* chinee *orange*)

Serial No.	Rootstock variety	No. of variants budded	Date of budding	Percentage 'take'	Average diameter of rootstock at the time of budding at 3 in. height (cm.)	Coefficient of variability of seedlings at the time of budding Per cent
1	Sweet orange	...	...	...	...	...
2	*Kichili*	54	7-1-37	87·30	0·88	10·51±0·01
3	*Gajanimma*	53	9-1-37	77·36	1·19	13·45±0·01
4	*Gabbu-chinee*	79	3-1-37	55·70	0·71	12·52±0·01
5	*Jamberi*	50	5-1-37	86·00	1·28	10·02±0·01
6	*Billi-kichili*	6	9-1-37	100·00	0·66	9·09±0·05
7	Pummelo	16	10-1-37	56·25	0·84	12·55±0·02
8	Acid lime	25	Do.	80·00	0·79	11·40±0·01
9	*Mokri*	23	Do.	69·57	0·86	12·56±0·02

Although the number of individuals worked were limited, and varied between varieties, the data in Table II nevertheless point out to the existence of fairly large differences between the several rootstock varieties in regard to the successful 'take' of *chinee* orange buds.

The data also show that the coefficient of variability in stem size of the variants is considerably less than what was found in the seedlings of the respective varieties two months before. This leads to the hope that the final set of seedlings selected for raising the experimental plants will be fairly uniform at least in so far as the measurements of stem thickness are concerned.

The preceding observations, however, require to be confirmed. This was done at the time of working the seedlings selected finally as the least variable in each rootstock variety.

Table III shows the mean increase in rootstock stem girth of the variants till the time of transplantation of budded plants to fresh nursery beds in July 1937.

TABLE III

Number of budded plants on most vigorous variant rootstocks and their mean growth increments till the time of their second transplantation in nursery beds

(*Rootstock trial for* chinee *orange*)

Serial No.	Rootstock variety	No. of plants	Mean increase in stem diameter cm.
1	Sweet orange	*Nil*	*Nil*
2	*Kichili*	34	0·308±0·045
3	*Gajanimma*	25	0·256±0·041
4	*Gabbu-chinee*	24	0·224±0·043
5	*Jamberi*	17	0·258±0·073
6	*Billi-kichili*	5	0·157
7	*Pummelo*	3	0·084
8	Acid lime	13	0·159±0·077
9	*Mokri*	6	0·183

The number of plants in pummeloes, *billi-kichili* and *mokri* is too few to be included for statistical test. In respect of other rootstock varieties, it is found that *kichili* has shown the largest rate of increase while *jamberi*, *gajanimma* and *gabbu-chinee* follow in the order in which they are given here.

In the following June 1937 when the measurements of trunk thickness of the unworked seedlings were collected, attempt was made to determine the extent of uniformity of these seedlings. The data are graphically represented in Fig. 1, which shows the frequency diagram and illustrates the distribution of trunk thickness of the seedlings of five of the rootstock varieties which had a large population in each. Of the five curves, *jamberi* alone gives a nearly normal curve with B2=2·9602, and B1=0·0813, but the theoretical curve does not give a good fit to observation. In other cases the curves approximate to Pearson's type I, but do not give a good fit to observed data, especially in the case of *gabbu-chinee*. The standard deviations range from 0·83 cm. in acid lime to 1·23 in *gabbu-chinee*.

Due to the high variability of the samples and in order to get uniformity in the materials, selections were made from the modal class only in the case of five rootstock varieties for budding. In other four varieties it was not possible to select individuals from modal class owing to the limited number of seedlings present. Table IV represents the number of individuals falling in the modal class and their trunk thickness.

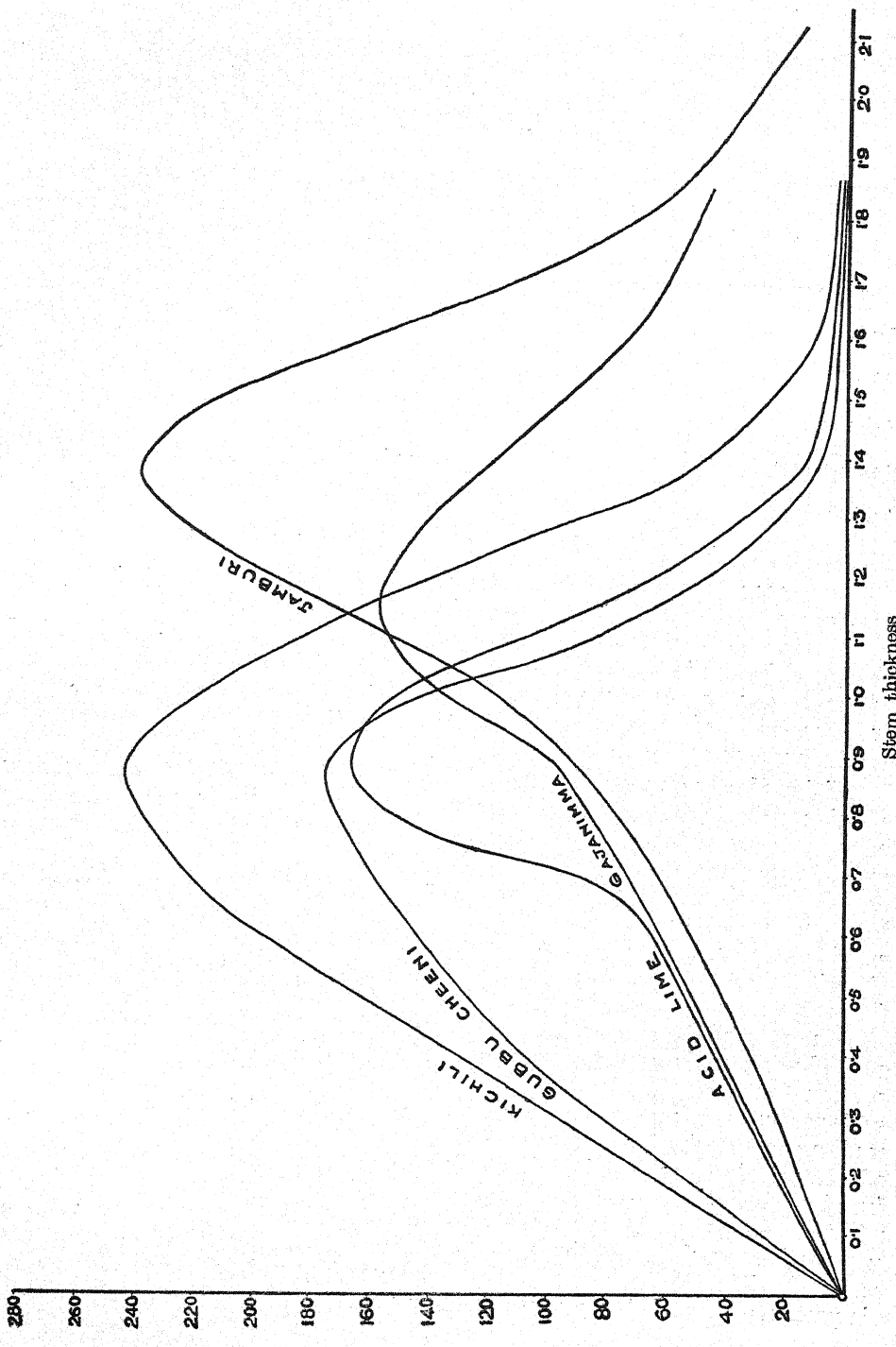

JAMBURI
KICHILI
GUBBU CHEENI
ACID LIME
ATANIMMA
Stem thickness
0·1 0·2 0·3 0·4 0·5 0·6 0·7 0·8 0·9 1·0 1·1 1·2 1·3 1·4 1·5 1·6 1·7 1·8 1·9 2·0 2·1
20 40 60 80 100 120 140 160 180 200 220 240 260 280

FIG. 1

TABLE IV

Number and proportion of seedlings in the modal class with central values and mean diameter measurements of different rootstocks

(*Rootstock trial for* chinee *orange*)

Rootstock variety	No. of individuals in modal class	Percentage of seedlings in modal class	Central value—diameter cm.	Mean value—diameter cm.
Jamberi	139	39·95	4·321	4·369
Kichili	228	39·72	2·750	2·797
Gajanimma	98	25·32	4·321	4·325
Gabbu-chinee	123	31·87	2·750	2·775
Acid lime	120	46·51	2·750	2·791

It is seen that *jamberi* and *gajanimma* have shown a greater stem thickness in the modal class than the seedlings of the other three varieties.

At the time of transplantation of seedlings from seed to the nursery beds, all the undersized and weak seedlings were rogued out once, and the rest were graded into three groups according to the size of the plants, and seedlings of each of these three grades were planted in separate but contiguous nursery beds.

Table V gives an idea of the extent of roguing out performed, number of plants falling under each grade and the significance of difference between the seedlings of each of these grades based on their stem girth measurement at the time of budding in July 1937.

It is evident from Table V that there is no significant difference between any of the grades in *gabbu-chinee*, *gajanimma* and acid lime, which therefore appear to be the least variable of all the five rootstocks. *Kichili*, on the other hand, appears to be most variable because of the significant difference between the A and B grades, and A and C grades.

In view of the repeated roguing out of the undersized and weak plants and of variants in seed and nursery beds respectively, and the further precaution taken in selecting only the individuals from the modal class in five varieties, no further steps appeared necessary for having the most uniform seedling rootstocks for the purpose of this trial. Nevertheless, as the number of individuals in the modal class of some of the varieties was large, it was found necessary to make a further selection of individuals out of those finally selected groups, so as to restrict the budding operation to a conveniently manageable number. Unfortunately, a uniform number of plants could not be obtained in the case of all rootstock varieties, mainly because of the inadequate number of plants raised in their case.

TABLE V

Extent of roguing out and proportion of seedlings under each grade of rootstocks with a comparison of their mean stem diameter measurements

(*Rootstock trial for* chinee *orange*)

Rootstock variety	Total No. of seedlings raised	Per cent rogued out	Percentage under each grade			Mean stem diameter at the time of budding			Significance of difference in respect of thickness between seedlings of		
			Height above 55 cm. A	Height between 26 & 55 cm. B	Height below 26 cm. C	A grade cm.	B grade cm.	C grade cm.	A & B	B & C	A & C
Jamberi	969	23·84	5·58	38·39	32·19	1·655	1·465	1·188	$P > \cdot 05$ not significant.	$P > \cdot 05$ not significant.	$P < \cdot 05$ significant but barely so.
Kichili	1,164	36·60	5·15	52·06	6·19	1·141	0·83	0·570	$P < \cdot 05$ significant.	$P > \cdot 05$ not significant.	$P < \cdot 05$ significant.
Gajanimma	1,008	43·34	8·35	41·17	7·14	1·323	1·232	0·956	$P > \cdot 05$ not significant.	$P > \cdot 05$ not significant.	$P > \cdot 05$ not singi. ficant.
Gabbu-chinee	1,143	35·42	1·57	46·20	16·80	0·886	0·768	0·688	$P > \cdot 05$ not significant.	$P > \cdot 05$ not significant.	$P > \cdot 05$ not significant.
Acid lime	510	14·51	10·20	61·17	14·12	0·951	0·949	0·783	$P > \cdot 05$ not significant.	$P > \cdot 05$ not significant.	$P > \cdot 05$ not significant.

In Table VI are presented the number of individuals finally budded, their mean girth, the coefficient of variability and the percentage 'take'. The budding was done by one operator with scions obtained from a single *chinee* orange tree from 4th to 12th July 1937.

TABLE VI

Percentage 'take' and mean stem diameter and variability at the time of budding chinee *on nine rootstocks*

(*Rootstock trial for* chinee *orange*)

Serial No.	Rootstock variety	Number budded	Date of budding	Percentgae 'take'	Average stem diameter at the time of budding (cm.)	Coefficient of variability per cent
1	*Chinee*	24	12-7-37	95·83	2·48	18·43
2	*Kichili*	50	7-7-37	88·00	2·66	5·00
3	*Gajanimma*	50	9-7-37	90·00	4·24	3·12
4	*Gabbu-chinee*	50	9-7-37	64·00	2·80	7·87
5	*Jamberi*	51	4-7-37	92·00	4·27	3·65
6	*Billi-kichili*	35	11-7-37	62·25	2·58	7·62
7	Pummelo	28	12-7-37	96·46	2·99	17.90
8	Acid lime	35	11-7-37	97·14	2·80	9·42
9	*Mokri*	30	12-7-37	96·67	2·92	23·63

The afore-mentioned data denote that the 'take' is very high on all varieties except on *gabbu-chinee* and *billi-kichili*.

Jamberi and *gajanimma* seedlings appear to have produced the most vigorous seedlings at the time of budding, while *chinee*, *billi-kichili* and *kichili* have produced the least vigorous individuals.

It has been pointed out in the previous pages that the selection of the plants in the nursery beds leads to considerable narrowing down of the co-efficient of variability. The figures in Table VI further substantiate this hypothesis, as except in *chinee*, pummelo and *mokri*, which contain a few individuals under each, the coefficient of variability has been reduced considerably by the repeated roguing out of the variants.

The finally selected budded plants of *chinee* orange on nine different rootstocks and seedlings of the same scion parent were planted out in their permanent orchard sites in October 1938. As stated already, *mokri* was replaced by *herale*, because of the availability of an insufficient number of uniform budded plants on the former rootstock at the time of planting. The latter rootstock was also raised almost at the same time and under similar conditions as those of the other eight rootstock varieties included in this trial.

The details of the experiment and materials, other than those referred to in the foregoing pages, are given in Table VII, while the analysis of the measurements of trunk thickness of all the plants at the time of planting and of the diameter and height increments from the time of budding to the time of final planting in the orchard are presented in Tables VIII-XI. In

TABLE VII

Some of the details of the trial with rootstocks for chinee *orange and of the materials used in the study*

(*Trial with rootstocks for* chinee *orange*)

1. Plot size . . . . . 120 ft. × 120 ft. (0·055 acre)
2. Number of plants in each plot . . . 3
3. Spacing . . . . . 28·28 feet (40 feet quincunx)
4. Number of replications 6
5. Scion tree used . . . . . *Chinee* (sweet orange), tree No. 10/4 in B. J. Garden at Kodur.
6. Performance of scion parent . . . . Yield :—No. of fruits

Year	Angam	Gairangam	Total
1935-36	950	50	1,000
1936-37	825	10	835

Name of rootstock	Key to treatment	Date of sowing	Date of primary transplantation	Extent of roguing in nursery beds *	Date of second transplantation	Date of final planting
Jamberi	A	12-11-35	25-6-36	40·00	6-6-38	10th to 13th October 1938
Gajanimma	B	17-11-35	30-6-36	40·00	8-6-38	Do.
Kichili	C	Do.	27-6-36	40·00	7-6-38	Do.
Billi-kichili	D	19-11-35	8-7-36	35·71	10-6-38	Do.
Gabbu-chinee	E	24-10-35	3-7-36	40·00	9-6-38	Do.
Pummelo	F	17-12-35	9-7-36	40·00	11-6-38	Do.
Herale	G	7-2-36	30-6-36	34·48	12-6-38	Do.
Acid lime	H	23-11-35	7-7-36	25·00	10-6-38	Do.
Chinee	I	Do.	18-9-36	40·00	11-6-38	Do.
Chinee seedling	J	27-12-35	Do.	25·00	15-6-38	Do.

* Extent of roguing in seed beds has been given in Table V.

TABLE VIII

Summary of results regarding the diameter measurements of rootstock stems at the time of final planting (Orange rootstock trial)

——	A	B	C	D	E	F	G	H	I	J	General mean	S. E. D. M.	Level of significance	Critical difference
Mean diameter per treatment in cm.	1·69	1·64	1·19	1·00	1·22	1·30	1·29	1·10	1·10	0·98	1·25	0·06	$P=0·05$	0·12
													$P=0·01$	0·16
Mean diameter as percentage of general mean	135·20	131·20	95·19	80·00	97·61	104·00	103·20	88·00	88·00	78·39	100·00	4·80	$P=0·05$	9·60
													$P=0·01$	12·80

Conclusion—

At 5 per cent level of significance :— A B F G E C I H D J

(Treatments under or above the same bar do not differ significantly from each other)

TABLE IX

Summary of results regarding the diameter measurements of scion stems at the time of final planting (Orange rootstock trial)

——	A	B	C	D	E	F	G	H	I	J	General mean	S. E. D. M.	Level of significance	Critical difference
Mean diameter of scion in cm.	1·22	0·95	0·77	0·61	0·84	0·60	0·79	0·51	0·72	0·98	0·80	0·05	$P=0·05$	0·11
													$P=0·01$	0·14
Mean diameter as percentage of general mean	152·50	118·80	96·25	76·25	105·00	75·01	98·74	63·75	89·99	122·50	100·00	6·87	$P=0·05$	13·75
													$P=0·01$	17·50

Conclusion—

At 5 per cent level of significance :— A J B E G C I D F H

(Treatments under or above the same bar do not differ significantly from each other)

TABLE X

Results regarding the height measurements of chinee *orange rootstock varieties and of* chinee *orange seedlings at the time of final planting*

(Orange rootstock trial)

——	A	B	C	D	E	F	G	H	I	J	General mean	S. E. D. M.	Level of significance	Critical difference
Mean height in cm.	56·70	43·17	35·28	28·34	43·14	29·56	40·25	25·72	35·97	42·08	38·02	3·33	$P=0·05$	6·53
													$P=0·01$	8·57
Mean height as percentage of general mean.	149·10	113·60	92·79	75·54	113·40	77·75	105·90	67·64	94·62	110·70	100·00	8·76	$P=0·05$	17·18
													$P=0·01$	22·54

Conclusion—

At 5 per cent level of significance :— A B E J G I C F D H

(Treatments under or above the same bar do not differ significantly from each other)

TABLE XI

Results regarding the increase in diameter of the rootstock and seedling stems from the time of budding till final planting

(Orange rootstock trial)

——	A	B	C	D	E	F	G	H	I	J	General mean	S. E. D. M.	Level of significance	Critical difference
Mean increase in diameter per treatment in cm.	0·37	0·31	0·33	0·17	0·33	0·19	0·08	0·17	0·35	0·75	0·30	0·05	$P=0·05$	0·11
													$P=0·01$	0·14
Mean increase in diameter as percentage of general mean	123·30	104·00	110·00	56·66	110·00	63·34	26·67	56·66	116·70	250·00	100·00	16·67	$P=0·05$	36·67
													$P=0·01$	46·67

Conclusion—

At 5 per cent level of significance :— J A I C E B F D H G

(Treatments under or above the same bar do not differ significantly from each other)

TABLE XII

Rootstock trial for acid limes

Rootstock variety	Germination	Time taken for germination in days	Per cent of seedlings from apogamic embryos, (calculated on 100 seeds)	Per cent of buddable plants available on 17th November 1936 (0·70 cm. and above)	Height measurements taken during November 1936		Diameter of stem during November 1936 (12 cm. ht.)	
					Average height	Coefficient of variability	Average diameter	Coefficient of variability
	per cent				cm.	per cent	cm.	per cent
1 *Kichili*	78·37	15	57·00	6·0	58·8	24·55±0·25	0·50	21·8 ±0·01
2 *Gajanimma*	63·00	19	23·00	22·0	47·9	29·65±0·96	0·56	28·57±0·01
3 *Jamberi*	79·00	18	29·00	94·0	61·9	25·31±1·32	0·68	25·00±0·01
4 *Gabbu-chinee*	70·00	17	2·07	..	44·0	27·09±0·80	0·41	23·41±0·01
5 Acid lime	80·00	20	38·66	3·0	54·6	22·43±0·83	0·45	26·22±0·01
6 Acid lime (unbudded)	80·00	20	38·66	3·0	54·6	22·43±0·83	0·45	26·22±0·01

NOTE.—Excepting in the case of *kichili* and acid lime, the seedlings raised for this trial are from parents which are different from those selected for rootstock trials for *chinee* orange.

the case of diameter measurements of budlings at the time of planting, the data have been collected at two different places, one around the rootstock stem at one inch below the bud-joint and another around the scion shoot one inch above the bud-union.

It is evident from these data that among the budded plants, *jamberi* is the most outstanding of all the rootstocks, since it has not only registered the highest increase in diameter of rootstock and scion stems but also has produced the largest sized plants at the time of final planting. Though *chinee* seedlings had a relatively poor stem thickness in comparison with other rootstocks at the commencement of their orchard life, they had recorded the largest trunk thickness increments during the preceding year. The latter feature can only be explained by the fact that the retarding influence of budding on growth was non-operating in its case.

Billi-kichili, acid lime, *chinee* and pummelo have produced the lowest sized plants at the time of planting, but trees on *chinee* rootstock had however registered very large growth increments during the preceding year to an extent comparable to the plants on *jamberi*. In respect of the size of the rootstock stems at the time of planting, *chinee* on *gajanimma* is almost on a par with that on *jamberi*.

2. Lime rootstock trial

In Table XII are given the data collected in seedbeds on seedlings of rootstocks raised for this trial.

The percentage ' take ' obtained by budding the variants during the third week of January, as well as the measure of variability in terms of rootstock stem diameter are given in Table XIII.

TABLE XIII

Percentage ' take ' of acid lime scion on some roostock variants with the rootstock size and variability

Rootstock variety	No. of variants budded	Date of budding	Percentage ' take '	Average diameter of stock at the time of budding 3 in height (cm.)	Coefficient of variability per cent
1 *Kichili*	52	18-1-37	11·54	0·75	11·20
2 *Gajanimma*	50	20-1-37	64·00	1·01	13·07
3 *Jamberi*	50	22-1-37	60·00	1·11	13·97
4 *Gabbu-chinee*	51	16-1-37	17·65	0·78	10·27
5 Acid lime	26	21-1-37	11·54	0·81	11·58

It is observed that all the five rootstock varieties have given a lower percentage ' take ' with acid lime scions than with scions of *chinee* orange. This variation is particularly noticeable on *kichili*, *gabbu-chinee* and acid lime. It has also been observed that the period taken for the acid lime buds to sprout was markedly greater than that taken by *chinee* buds on similar rootstock varieties. These observations appear to point out to the existence of differential extent of congeniality in the different combinations of rootstock and scion varieties ; or in other words, different scion varieties appear to respond differently on a given rootstock variety.

As in the rootstock trial for *chinee* orange, the extent of variability in the variant seedlings of all the rootstock varieties have been considerably narrowed down as a result of selection.

The number of vigorous growing seedling variants selected for budding in this experiment was limited, and except in the case of *jamberi* and *gajanimma*, the stem diameter records have not been collected as in the case of orange scion. The number of the budded variants on *gajanimma* was 17 and on *jamberi* 16, and the increase in stem diameter from the date of bud-insertion on 20th January 1937 to the date of primary transplantation on 16th July 1937 was 0·88 cm. and 0·82 cm. respectively.

The number of individuals in the modal class of each of these rootstock varieties along with their central values are given in Table XIV.

TABLE XIV

Proportion of seedlings in the modal class with mean and central stem diameter value

(*Rootstock trial for acid limes*)

Serial No.	Rootstock variety	No. of individuals in the modal class	Percentage of seedlings in the modal class	Central value diameter cm.	Mean value diameter cm.
1	*Kichili*	228	39·72	2·75	2·797
2	*Gajanimma*	83*	..	..	3·583
3	*Jamberi*	84*	..	..	2·274
4	*Gabbu-chinee*	114	36·30	2·75	2·816
5	Acid lime	120	46·51	2·75	2·766

* Due to limited number of individuals, the seedlings having the narrowest range of variation were selected in these varieties.

Table XV shows the final number of individuals budded to acid lime, their mean stem diameter, coefficient of variability and the percentage ' take '. In this case too, the budding was done by one and the same operator as in orange rootstock trial.

TABLE XV

Percentage 'take' with acid lime scion and average stem diameter and variability of rootstocks

Serial No.	Rootstock variety	Number budded	Date of budding	Percentage 'take'	Average diameter at the time of budding in cm.	Coefficient of variability percentage
1	*Kichili*	50	16-7-37	18·0	2·76	9·40
2	*Gajanimma*	50	18-7-37	50·0	3·68	4·84
3	*Jamberi*	57	15-7-37	42·0	4·35	18·00
4	*Gabbu-chinee*	50	19-7-37	16·0	2·62	8·68
5	Acid lime	35	14-7-37	80·8	2·86	11·60

Due to the limited number of budded individuals on *kichili* and *gabbu-chinee*, these two rootstock varieties had to be left out of the trial. Uniform and healthy budlings of acid lime on the remaining three rootstocks, viz. *jamberi*, *gajanimma* and acid lime, and seedlings of the same scion parent were finally selected and planted out in their permanent orchard sites in October 1938 according to the layout described already.

Details of the plant material used, key to treatments, etc. are furnished in Table XVI.

TABLE XVI

Key to treatment, details of plant material used, layout, etc.

(*Rootstock trial for acid limes*)

1. Plot size — 60 ft. × 20 ft. (0·0275 acre)
2. Number of replications — 6
3. Number of trees in each plot — 3
4. Spacing — 20 feet (square).
5. Scion material used — Acid lime ; tree No. 4/6, N. K. Garden, Kodur
6. Scion performance —

Yield	Number of fruits
1935-36	2,000
1936-37	2,500

7. Date of planting — 20th to 21st October 1938.

Rootstock variety	Key to treatments	Date of sowing	Extent of roguing out in seed-beds (per cent)	Date of primary transplantation	Extent of roguing out in nursery beds (per cent)	Date of budding	Date of second transplantation
Jamberi . .	A	19-12-35	*Nil*	3-7-36	40·00	15-7-37	13-6-38
Gajanimma .	B	18-11-35	52·50	1-7-36	40·00	18-7-37	14-6-38
Acid lime . .	C	23-11-35	14·50	7-7-36	40·00	14-7-37	14-6-38
Acid lime (seedling)	D	23-11-35	14·50	7-7-36	40·00	...	15-6-38

TABLE XVII

Summary of results regarding the diameter measurements of rootstock stems and of stems of seedling trees at the time of final planting

(*Acid lime rootstock trial*)

	A	B	C	D	General mean	S. E. D. M.	Level of significance	Critical difference
Mean diameter per treatment in cm.	1·95	1·56	1·22	1·49	1·55	0·06	$P=0·05$ $P=0·01$	0·12 0·17
Mean diameter as per cent of the general mean	125·80	100·70	78·72	96·14	100·00	3·87	$P=0·05$ $P=0·01$	7·74 10·96

Conclusion.—At 5 per cent level of significance :—A $\overline{\text{B D}}$ C
(Treatments under the same bar do not differ significantly from each other)

TABLE XVIII

Summary of results regarding the scion stem diameter at the time of final planting

(*Acid lime rootstock trial*)

	A	B	C	D	General mean	S. E. D. M.	Level of significance	Critical difference
Mean diameter in cm.	1·42	0·92	0·71	1·48	1·13	0·08	$P=0·05$ $P=0·01$	0·16 0·23
Mean diameter as per cent of general mean	125·70	81·41	62·84	131·00	100·00	7·08	$P=0·05$ $P=0·01$	14·16 20·35

Conclusion.—At 5 per cent level of significance :—$\overline{\text{D A}}$ B C
(Treatments under the same bar do not differ significantly from each other)

TABLE XIX

Summary of results regarding height measurements of the plants at the time of final planting
(Acid lime rootstock trial)

	A	B	C	D	General mean	S. E. D. M.	Level of significance	Critical difference
Mean height in cm. . .	84·67	55·00	43·50	73·22	64·10	6·96	$P=0·05$ $P=0·01$	14·84 20·51
Mean height of the plants as per cent of general mean	132·10	85·80	67·85	114·20	100·00	10·86	$P=0·05$ $P=0·01$	23·15 32·00

Conclusion.—At 5 per cent level of significance :—$\overline{A \quad D} \quad \overline{B \quad C}$
(Treatments under the same bar do not differ significantly from each other)

TABLE XX

Summary of results regarding the increase in stem thickness of the various rootstocks from the time of budding till final planting
(Acid lime rootstock trial)

	A	B	C	D	General mean	S. E. D. M.	Level of significance	Critical difference
Mean increase in diameter in cm.	0·53	0·36	0·25	0·52	0·41	0·09	$P=0·05$ $P=0·01$	0·19 0·27
Mean increase in diameter as per cent of general mean	129·30	87·80	60·96	126·90	100·00	21·95	$P=0·05$ $P=0·01$	46·34 65·86

Conclusion.—At 5 per cent level of significance :—$\overline{A \quad D \quad B} \quad C$
(Treatments under the same bar do not differ significantly from each other)

As in the *chinee* orange rootstock trial, stem diameter and height measurements of the plants collected at the time of final planting and the stem diameter increments from the time of budding to that of final planting have been analysed, and these are set forth in Tables XVII—XX.

These various data make it clear that *jamberi* has produced the largest rootstock stem thickness at the time of planting, while acid lime rootstock has produced the least. During the pre-orchard life also the latter has produced the smallest growth increments in regard to rootstock stems, but no significant difference is evident between it and *gajanimma* rootstock. With regard to the stem thickness of the seedlings and the scions, it is found that *jamberi* and acid lime seedlings have produced the largest increments at the time of final planting whereas the plants on acid lime and *gajanimma* rootstocks have occupied the lowest ranks.

3. Citrus root studies

The data and observations collected from root excavations carried out during 1936-37 are given in Table XXI.

It is seen from the data presented herein that a collection of seedlings of any of the varieties include plants of differing root habit.

In spite of this range of variation, certain specific or varietal characters are indicated from these data especially in regard to depth of root, the quantity and distribution of fibrous and lateral roots, extent of branching of roots and the stem : root ratio. From these preliminary studies, the following different types of root systems appear to be associated with different varieties :—

Kichili :—Stout but comparatively short laterals ; deeply anchored. Branching of roots mainly towards the extremities of the main tap-roots. Sparsely fibred in the upper soil layers but moderately fibrous towards the lower ends. Appears to make relatively dwarf plants in the nursery in proportion to depth of roots.

Gajanimma :—Very stout tap-root and few laterals on the upper layers, but these are well distributed. Noticeably free in sending out new adventitious roots. Fairly abundant and well distributed fibre throughout the root system. Deep rooted.

Jamberi :—Abundance of coarse and spreading laterals, with a good amount of well distributed fibre. Stout and deeply anchored tap-root. Spread of laterals more marked than in *gajanimma* and *kichili* and with more abundant fibre, a good proportion of which is confined to surface.

Pummelo :—A compact root system with many strong and spreading laterals. Well fibred. Has a short but stout tap-root. Appears to have a tendency to grow somewhat horizontally in the upper layers of soil. Makes the largest top growth in nursery in proportion to root depth among all the varieties.

Acid lime :—Medium to small root system. Fibre sparse except towards the extremities, where coarse laterals are fairly well supplied with fibre. Tap-root thin.

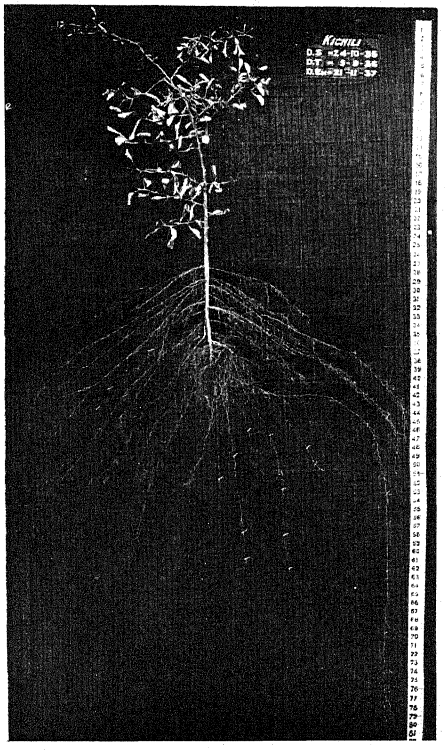


FIG. 1

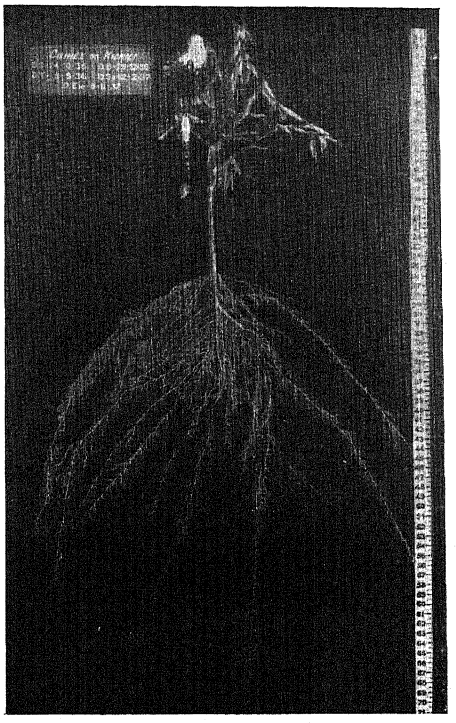


FIG. 2

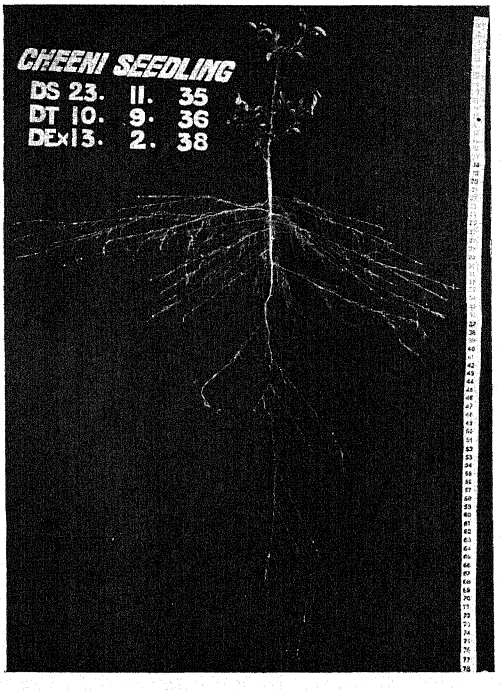


FIG. 3

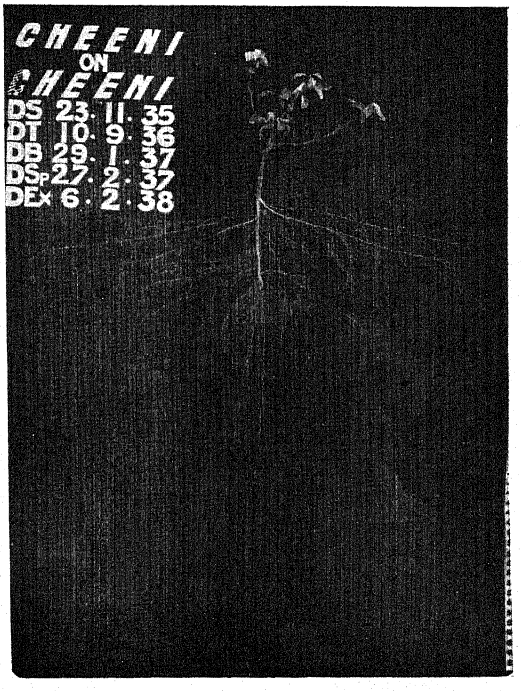


FIG. 4

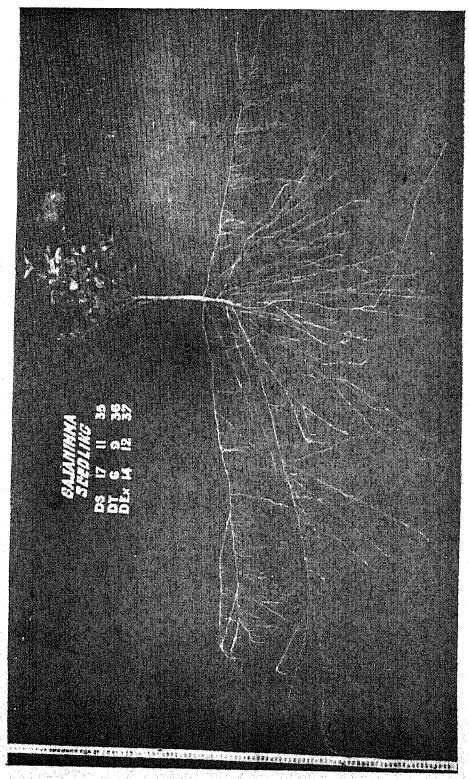


FIG. 1

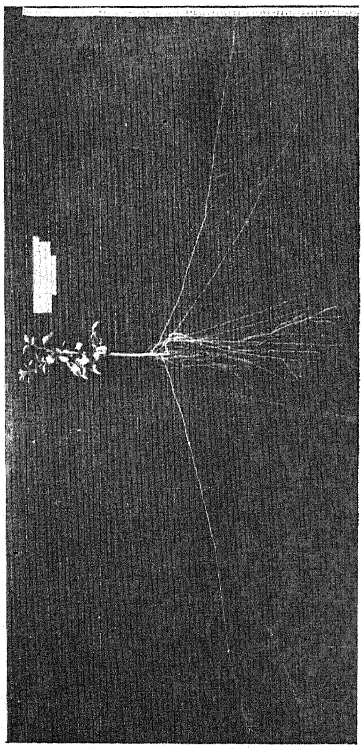


FIG. 2

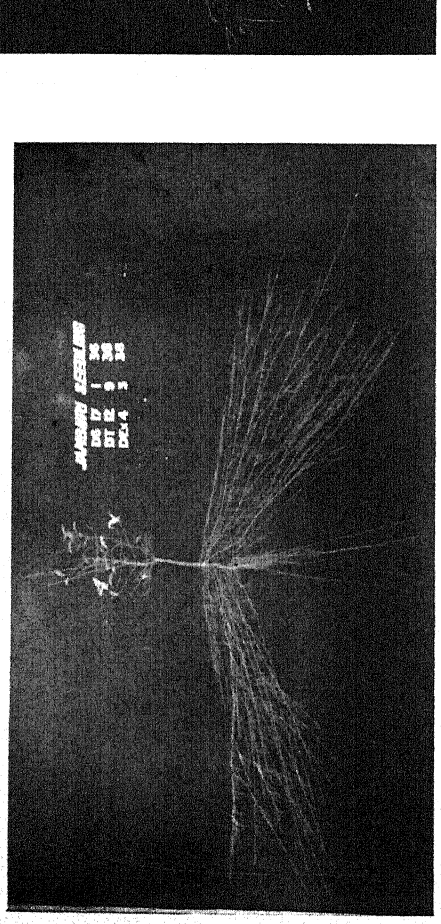


FIG. 3

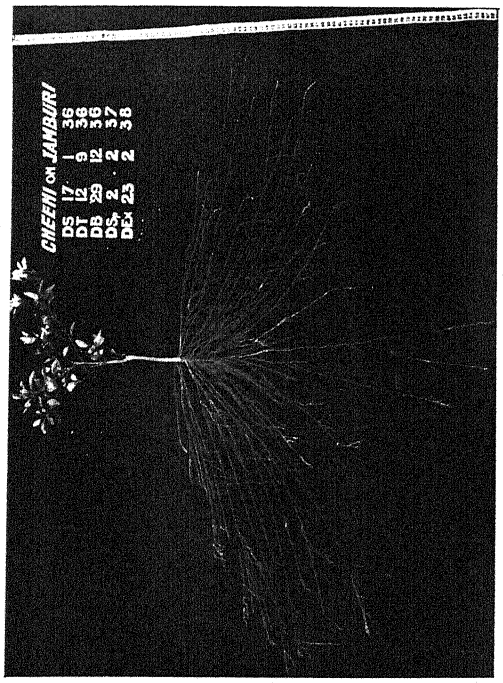


FIG. 4

TABLE XXI

Records on root system of citrus seedlings (1936-37)

No.	Variety	Age of seedling on the day of study	Depth of root cm.	Greatest length of laterals cm.	Shoot wt. / Root wt. Ratio	Ht. of shoot / Root length Ratio	Number of laterals: Up to 3 in.	Between 3 in. and 6 in.	Between 6 in. and 9 in.
		M. Days							
1	*Kichili*	(*a*) 8 19	115·0	16·0	1·08	0·27	16	19	20
		(*b*) 8 19	121·0	18·0	1·07	0·28	16	24	27
		(*c*) 8 19	126·0	10·1	1·11	0·30	20	26	27
2	*Gajanimma*	(*a*) 6 18	137·0	40·0	1·46	0·39	6	25	10
		(*b*) 6 18	111·0	31·0	0·76	0·37	6	14	10
		(*c*) 6 18	110·0	25·0	0·43	0·27	14	20	12
3	*Jamberi*	(*a*) 8 6	111·5	45·1	1·07	0·62	28	39	42
		(*b*) 8 6	107·5	41·0	1·17	0·58	18	28	26
		(*c*) 8 6	102·5	45·5	0·86	0·56	20	35	40
4	Pummelo	(*a*) 7 25	73·1	60·5	2·11	0·75	28	40	20
		(*b*) 7 25	34·0	37·5	1·39	1·21	15	38	15
		(*c*) 7 25	32·5	55·2	0·90	1·40	20	35	15
5	Acid lime	(*a*) 9 2	108·0	68·2	1·25	0·64	14	26	12
		(*b*) 9 2	94·3	28·1	1·61	0·65	19	17	16
		(*c*) 9 2	78·1	48·5	1·07	0·74	26	36	13
6	*Gabbu-chinee*	(*a*) 10 2	189·8	12·0	0·68	0·25	11	17	15
		(*b*) 10 2	124·0	12·1	0·75	0·35	14	19	17
		(*c*) 10 2	72·2	42·7	0·76	0·53	23	19	25
7	Sweet orange (*chinee*)	(*a*) 7 28	120·0	44·0	1·37	0·40	26	14	24
		(*b*) 7 28	91·0	48·5	1·31	0·58	20	22	18
		(*c*) 7 28	87·5	46·2	1·08	0·43	16	16	17
8	*Billi-kichili*	(*a*) 10 4	94·8	24·2	1·32	0·48	6	23	21
		(*b*) 10 4	89·0	17·3	1·36	0·43	16	17	16
		(*c*) 10 4	75·7	44·0	1·17	0·46	12	20	24

Gabbu-chinee :—The largest tap-root extending up to 189·8 cm. from soil surface was found in this variety. Roots appear bare in comparison with other varieties. The tap-root fairly thin. Sparse and poor spreading laterals with little fibre.

Sweet orange (*chinee*) :—Well balanced root system between medium coarse laterals and moderately abundant fibre. Stout tap-root. A large proportion of spreading laterals and fibre in upper layers of soil.

Billi-kichili :—Resembles *gabbu-chinee*, except that in this variety the roots are less penetrating and have slightly better spreading laterals. Fair amount of fibre towards the lower soil layers.

A point of interest revealed from this study is the enormous depth to which the roots of some of the citrus varieties find their way at a very early stage of their life in the seed beds. The close planting in seed beds is undoubtedly the primary cause for this root habit. Since the roots are usually pruned to a depth of 15 to 30 cm. at the time of transplantation, the study indicates the enormous extent of pruning (in one instance as much as about 160 cm.) given to the roots.

In addition to the above-mentioned studies, 45 more root systems of seedlings of different varieties of citrus were also examined at different periods. The observations made on these plants appeared to confirm, in general, the descriptions summarised above.

In Table XXII are given the percentage of success obtained by transplanting the seedlings of these eight different varieties during the same year.

TABLE XXII

Percentage of living plants in different varieties of citrus after transplantation

Serial No.	Variety	Date of sowing	Date of transplanting	No. of seedlings transplanted	Percentage of success
1	*Kichili* . . .	17-11-35	27-6-36	788	89·88
2	*Gajanimma* . .	17-11-35	30-6-36	612	87·75
3	*Gajanimma* . .	18-11-35	1-7-36	414	86·71
4	*Jamberi* . . .	12-11-35	25-6-36	738	97·15
5	*Jamberi* . . .	19-12-35	3-7-36	84	95·23
6	Pummelo . . .	17-12-35	9-7-36	42	100·00
7	Acid lime . . .	23-11-35	7-7-36	436	73·39
8	*Gabbu-chinee* . .	24-10-35	3-7-36	807	67·41
9	*Gabbu-chinee* . .	24-10-35	5-7-36	833	56·42
10	Sweet orange (*chinee*)	23-11-35	9-7-36	36	100·00
11	*Billi-kichili* . .	19-11-35	8-7-36	109	64·22

From a reference to Tables XXI and XXII and descriptions of root systems, it appears possible that the success in transplanting is dependent upon the character of the root system. An abundance of fibre in the upper soil layer or shallow scaffolding of laterals appear to be favourable for ensuring a good stand.

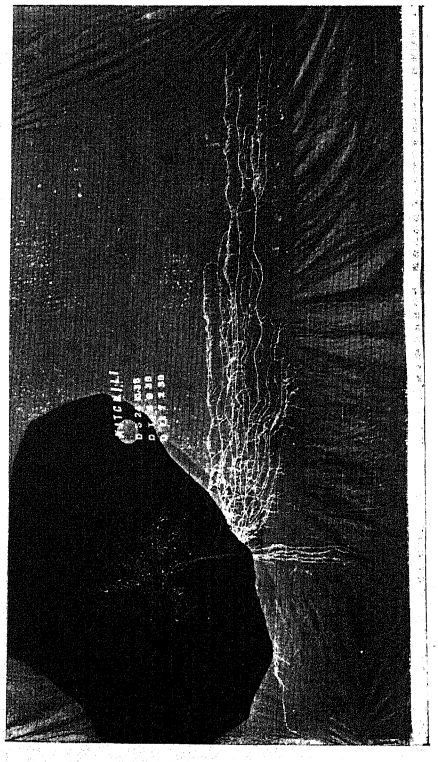


FIG. 1

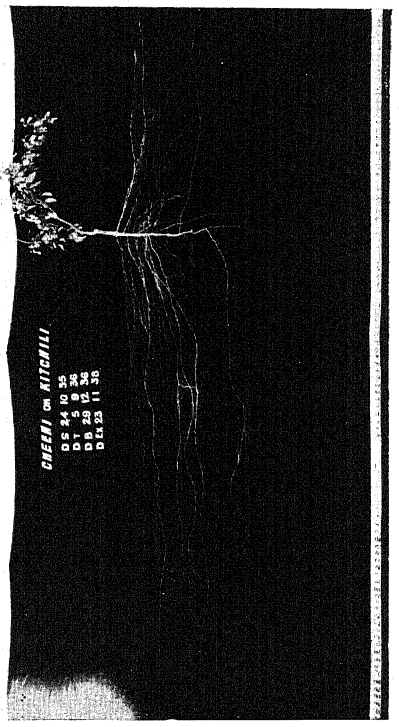


FIG. 2

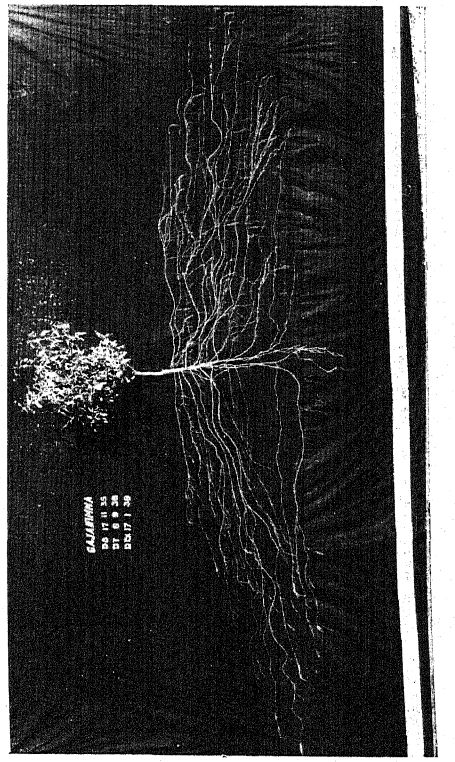


FIG. 3

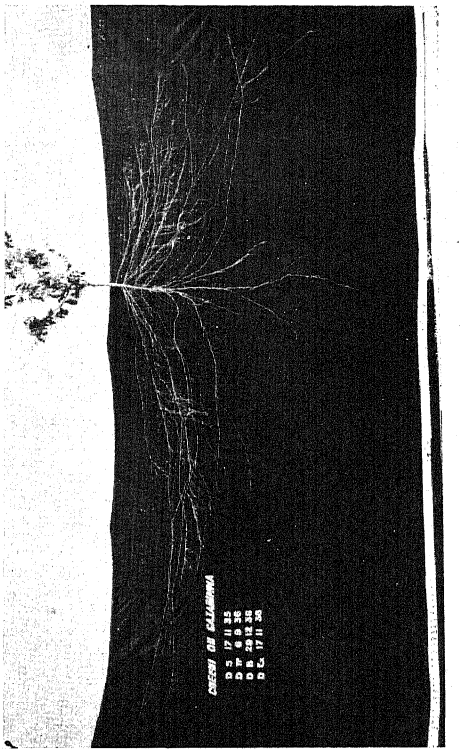


FIG. 4

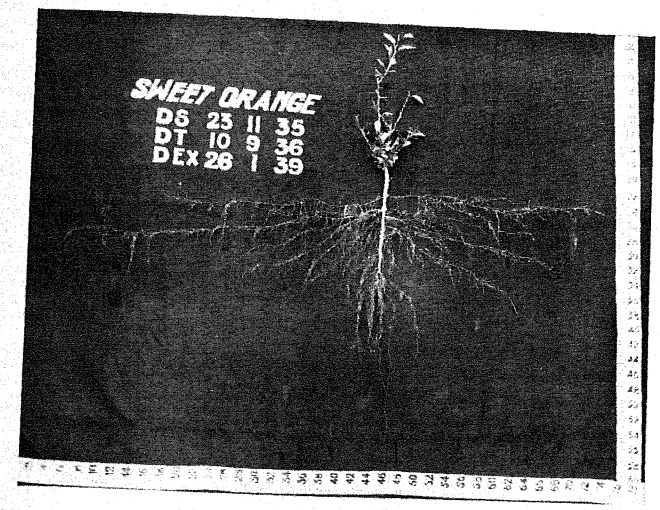


FIG. 1

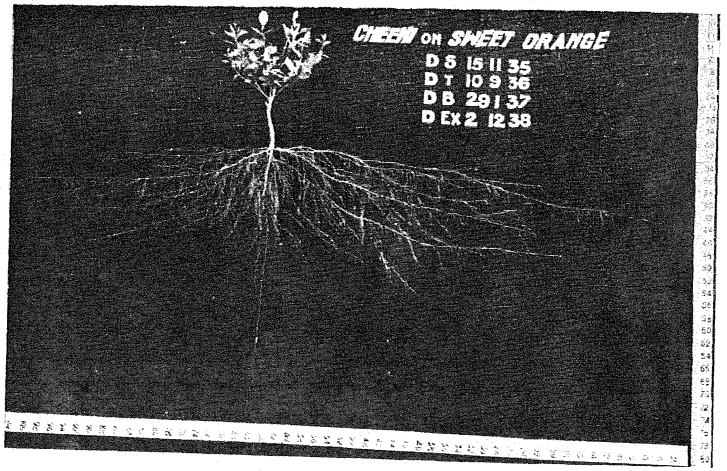


FIG. 2

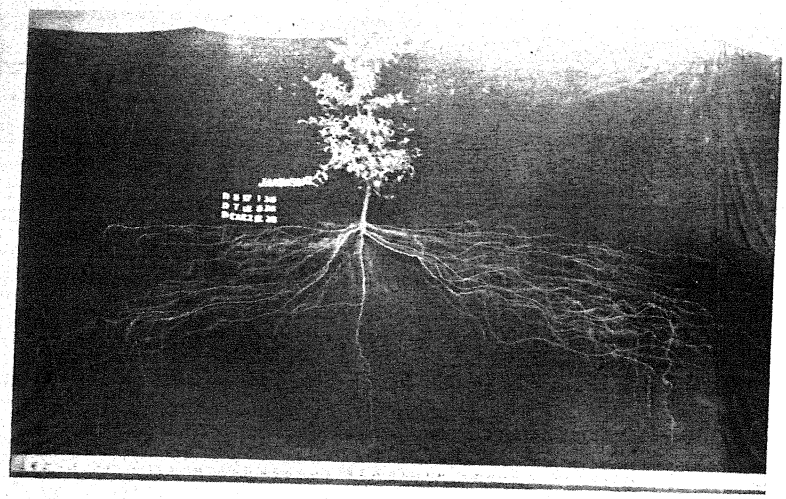


FIG. 3

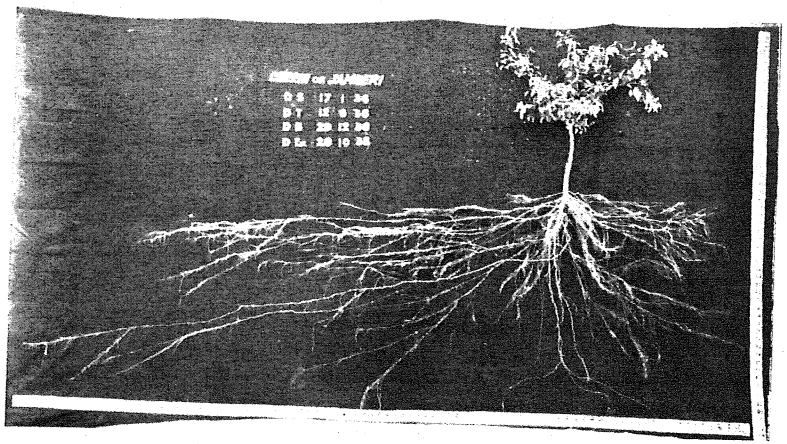


FIG. 4

During the period, October 1937 to March 1938 and again during 1938-39, one budded *chinee* orange plant on each of the eight rootstocks and an unworked seedling of the same rootstock variety, out of the batches of plants specially raised for this purpose were excavated for a study of root systems (Plates XVIII—XXI). The data collected in the course of former root excavations are summarised in Tables XXIII and XXIV.

It is realised that the data furnished in Tables XXIII and XXIV are not sufficient to gather an accurate idea about the varietal characteristics or of the peculiar habits of the unworked or budded plants on any given variety. Notwithstanding these limitations, the outstanding differences observed in these root excavations are considered to be of sufficient interest to be summarised in the present paper as will also be evident from the perusal of the following inferences.

(*a*) In the case of *gabbu-chinee* and country sour orange rootstocks, the height of the bud-sprouts has shown to be even more than the height of the unworked seedlings. Whether this surprising fact is due to the variation in the individuals or due to invigorating effect of these particular stock-scion combinations, it will be impossible to clearly state on the basis of the variable data.

(*b*) Of all the varieties, sweet orange has shown the least growth in terms of height both as an unworked seedling and as a rootstock.

(*c*) In regard to stem diameter measurements, *kichili* has shown relatively poor growth both in worked and unworked seedlings.

(*d*) The total weight of the plants above ground is found to be more in budded plants on country sour orange and *jamberi* than in the unworked seedlings of these varieties. This, again, is at present an inexplicable point. Sweet orange, country sour orange and *kichili* have registered relatively low weight of top growth, both in the case of unworked seedlings and when used as rootstocks for orange.

(*e*) Except on *gajanimma*, pummelo and sweet orange, the budded plants have penetrated into greater depths of soil than the unworked seedlings. *Kichili*, however, has proved to be relatively shallow rooted both as an unworked seedling and as a rootstock for sweet orange, while country sour orange and *khatta* are on the other extreme.

(*f*) The budded plants on *gajanimma* and *gabbu-chinee* have foraged on a large area than the seedlings of these two varieties. Both the worked and unworked seedlings of *gajanimma* and *khatta* have recorded relatively large spread of roots, while *kichili* and orange have recorded the least in both cases.

(*g*) *Kichili*, *gabbu-chinee* and sweet orange have shown a larger number of laterals when employed as rootstocks than as seedlings. The number of lateral roots is relatively large on both worked and unworked seedlings of *jamberi* and *khatta*, and relatively small in *kichili*.

TABLE XXIII

Records on root systems of unworked seedlings of different varieties of citrus

Variety	Date of excavation	Age at the time of excavation		Height of plants	Girth at 3 in. height from the ground	Weight of shoots	Depth of roots	Spread of roots	Maximum length of lateral roots	No. of laterals	Total weight of roots	Weight of coarse roots	Weight of fibrous roots	Weight of fibre as percentage of total weight of roots	Shoot weight / Root weight Ratio
		Month	Days	cm.	cm.	gm.	cm.	cm.	cm.		gm.	gm.	gm.		
Kichili .	21-11-37	24	27	87·00	3·77	59·6	87·0	150·0	82·0	61	37·9	25·6	12·3	32·47	1·57
Gajanimma	14-12-37	24	27	100·00	6·29	278·0	151·0	410·0	262·0	173	249·0	151·0	98·0	39·36	1·12
Gabbu-chinee	29-11-37	25	9	75·00	5·72	92·0	125·5	264·0	145·0	115	148·0	95·0	53·0	35·81	0·62
Khatta .	31-1-38	25	13	120·00	6·60	271·0	142·0	500·0	270·0	195	373·0	233·0	140·0	37·50	0·75
Pummelo*	10-2-38	25	23	115·00	5·88	165·0	176·0	260·0	130·0	150	232·0	112·0	120·0	51·72	0·71
Sweet orange	13-2-38	26	20	56·50	3·61	40·0	143·0	140·0	80·0	110	60·0	24·0	36·0	60·00	0·67
Sour country orange	19-2-38	26	0	46·00	3·42	48·0	150·0	251·0	130·0	148	65·9	29·6	36·3	55·08	0·73
Jamberi .	4-3-38	25	17	110·00	5·37	119·0	126·0	400·0	235·0	178	295·0	180·0	115·0	38·98	0·40

* The root system of this plant is not normal for the reason given elsewhere.

TABLE XXIV

Records on root systems of chinee *orange plants on different rootstocks*

Rootstock variety	Date of excavation	Age of scion at the time of excavation in months and days	Age of stock at the time of excavation in months and days	Height of bud-sprouts in cm.	Girth of scion at 1 in. above the point of insertion, in cm.	Girth of stock at 3 in. above the ground level in cm.	Weight of scion in gm.	Weight of stock in gm.	Total weight of plant above the ground level in gm.	Depth of roots in cm.	Spread of roots in cm.	Maximum length of laterals in cm.	Number of laterals	Total weight of roots in gm.	Weight of coarse roots in gm.	Weight of fibre roots in gm.	Weight of fibre as percentage of total weight of roots	Ratio:— Shoot weight / Root weight
Kichili	8-11-37	10 9	24 10	46·8	1·87	2·73	28·00	16·95	44·95	120·0	102·5	60·5	66	34·4	23·8	10·6	30·52	1·31
Gajanimma	24-11-37	10 25	24 7	58·6	2·64	5·09	46·80	16·50	63·30	117·0	425·0	225·0	63	93·0	66·0	27·0	29·03	0·68
Gabbu-chinee	21-1-38	12 22	26 23	93·0	3·08	6·66	59·00	25·60	84·60	139·0	285·0	185·0	173	137·2	78·1	59·1	43·08	0·63
Khatta	4-12-37	10 22	23 16	60·5	3·52	5·91	83·00	47·00	130·00	145·3	415·0	230·0	150	169·0	114·0	55·0	32·54	0·73
Pummelo	4-2-38	12 22	25 17	63·5	2·51	4·53	32·00	27·00	59·00	115·5	210·0	150·0	120	108·0	43·0	65·0	60·19	0·55
Sweet orange	27-2-38	12 28	27 4	34·5	2·36	3·56	10·00	9·50	19·50	99·0	125·0	69·5	124	42·5	23·0	19·5	45·88	0·46
Sour country orange*	8-3-38	14 9	26 20	63·0	2·98	3·82	34·00	19·00	53·00	160·0	235·0	201·0	130	62·0	43·0	19·0	30·65	0·85
Jamberi	23-2-38	13 29	25 6	56·0	3·90	4·93	80·00	50·00	130·00	150·0	200·0	165·0	153	145·0	100·0	45·0	31·03	

* The root system of this plant is not normal for the reason given elsewhere.

(*h*) The total weight of the roots has apparently been considerably reduced in worked seedlings of *gajanimma*, *khatta*, pummelo and *jamberi*. Both the worked and unworked seedlings of *khatta* and *jamberi* have produced relatively heavier root systems, while *kichili*, sweet orange and country sour orange have produced relatively lighter roots.

(*i*) The weight of fibrous roots is observed to be more on worked seedling of *gabbu-chinee* than in the case of unworked. Marked reduction in the weight of fibre is noticed in the worked seedlings of *gajanimma*, pummelo and *jamberi*.

(*j*) In proportion to the entire root system, the fibre is more on worked seedlings of *gabbu-chinee* and pummelo than on unworked. The proportion of fibrous roots is found to be relatively large on both the worked and unworked seedlings of pummelo and sweet orange, and low in *kichili*, *jamberi* and *khatta*.

(*k*) In relation to root, the top-growth has registered larger increase on worked seedlings of *gabbu-chinee*, country sour orange and *jamberi* than on unworked, while it remains the same in the case of *khatta*. *Kichili* has shown a larger top-growth in proportion to root, both as a rootstock as well as an unworked seedling, while sweet orange has shown proportionately the least top-growth in both the classes.

In the case of *kichili* seedling (Plate XX, fig. 1) and the budded orange on *jamberi* (Plate XXI, fig. 4), they were planted close to pits which had been dug about six months before their planting. The pits had been refilled a short while before the planting of the trees. The loose media inside these pits has obviously brought about a marked influence on the root growth. The large increase in the size and number of lateral and fibrous roots inside the dug-out area on one side of the figure as contrasted with the normal development in the rest of the soil serves to emphasize the considerable influence that soil conditions exert on the root system of plants.

The excavation and study of root system was repeated during 1938-39 and the observations collected during that year are set forth in Tables XXV and XXVI.

The following inferences seem to be warranted from the data :—

(1) Sweet orange has produced the smallest top growth in terms of height and stem thickness both as an unworked seedling and as a rootstock during the two years under study. This observation is further confirmed by the data relating to the weight of plants above ground level. In this respect, *gajanimma*, *jamberi* and *khatta* would seem to mark the other extreme in producing the largest weight of top growth.

(2) Almost the same position as that mentioned above has been maintained by sweet orange both as an unworked seedling and as a rootstock in regard to the depth and spread of roots, total weight of roots, weight of coarse roots and weight of fibrous roots, whereas *jambari*, *khatta* and *gajanimma* maintain the premier position in regard to these characters.

TABLE XXV

Records on root systems of unworked seedlings of different rootstock varieties

(Citrus root studies)

Variety	Date of excavation	Age at the time of the excavation	Height of the plant	Stem thickness at 3" from ground level	Weight of the shoot	Depth of the roots	Spread of the roots	Maximum length of the laterals	Total weight of roots	Weight of coarse roots	Weight of fibrous roots	Weight of fibre as per cent of the total weight of roots	Shoot weight / Root weight Ratio
		M. Days	cm.	cm.	gm.	cm.	cm.	cm.	gm.	gm.	gm.	gm.	
Gabbu-chinee	10-12-38	37 12	102·50	1·47	204·50	146·50	411·30	245·00	171·17	136·70	34·47	20·10	1·19
Khatta	18-12-38	36 0	154·30	3·21	1,192·00	147·25	617·00	400·00	500·50	430·00	70·50	14·10	2·36
Jamberi	22-12-38	35 5	168·00	3·20	1,283·70	190·40	441·80	405·00	680·50	595·00	85·50	12·56	1·88
Gajanimma	17-1-39	38 0	131·00	3·60	1,383·50	160·00	639·80	350·40	509·50	475·00	34·50	6·70	2·71
Sweet orange	25-1-39	38 3	50·70	1·13	49·00	91·40	177·70	101·50	49·00	31·00	18·00	36·70	1·00
Country orange	31-1-39	37 23	134·60	2·70	616·50	320·00	512·80	256·40	240·00	190·00	50·00	20·80	2·56
Pummelo	2-2-39	37 16	127·00	2·23	430·00	142·20	304·70	667·60	200·00	140·00	60·00	30·00	2·15
Kichili	7-2-39	39 13	104·00	1·70	366·00	134·60	563·60	446·70	198·00	169·00	29·00	14·60	1·85

TABLE XXVI

Records on root systems of chinee *orange plants on different rootstocks*
(Citrus root studies)

Variety.	Date of excavation	Age of scion at the time of excavation, in months and days	Age of rootstock at the time of excavation in months and days	Height of bud-sprout	Stem thickness of the scion at 1 in. above bud-joint	Stem thickness of the rootstock at 3 in. above ground level	Weight of scion	Weight of rootstock	Total weight of plant	Depth of roots	Spread of roots	Maximum length of laterals	Total weight of roots	Weight of course roots	Weight of fibrous roots	Weight of fibre as percentage of total weight of roots	Ratio:— Shoot weight / Root weight
				cm.	cm.	cm.	gm.	gm.	gm.	cm.	cm.	cm.	gm.	gm.	gm.		
Gabbu-chinee	12-10-38 to 16-10-38	21 14	35 17	73·66	1·62	1·62	85·71	35·71	121·42	127·00	386·00	218·44	85·00	64·28	21·42	25·00	1·42
Khatta	20-10-38 to 25-10-38	23 5	23 28	76·50	2·50	1·90	321·00	57·00	378·00	120·00	441·40	329·00	155·00	127·00	27·50	17·70	2·44
Jamberi	26-10-38 to 6-11-38	21 7	34 9	97·80	2·79	3·10	565·80	95·00	660·80	147·50	378·30	418·00	356·26	294·50	61·76	17·30	1·85
Gajanimma	10-11-38	21 11	36 5	97·50	1·98	2·72	415·00	74·00	489·00	256·40	543·30	398·60	276·00	238·50	37·50	13·58	1·77
Sweet orange	2-12-38	22 20	36 9	56·70	1·42	1·78	89·00	16·00	105·00	117·00	246·20	167·60	72·00	47·00	25·00	34·72	1·46
Country orange	29-11-38	23 0	35 2	80·00	1·42	1·86	186·00	42·00	228·00	132·00	414·00	304·80	175·00	140·00	35·00	20·00	1·13
Pummelo	5-12-38	22 6	35 18	53·30	0·84	1·64	73·00	29·00	102·00	132·10	256·40	134·60	78·00	53·00	25·00	32·05	1·31
Kichili	23-11-38	21 24	37 3	91·50	1·89	2·50	401·00	62·00	463·00	147·20	472·20	391·00	244·82	216·00	28·82	11·77	1·89

(3) As against all other rootstocks and unworked seedlings, sweet orange seedling and rootstock have produced the maximum percentage of fibre in the root system in both the years under study as well as possessed a greater root weight in proportion to the top weight. *Kichili* and *gajanimma*, when employed as rootstocks, on the other hand, have produced the least proportion of fibre in both the years. Pummelo perhaps comes close to sweet orange in regard to this character.

(4) *Jamberi*, *gajanimma*, sweet orange and country orange have registered a greater length of lateral roots when employed as rootstocks than as unworked seedlings. In a similar manner, *gajanimma*, sweet orange and *kichili* have penetrated to a greater depth when used as rootstocks. The percentage of fibre in budded plants has also been greater on *gabbu-chinee*, *khatta*, *jamberi*, *gajanimma* and pummelo than on unworked seedlings, while a relatively greater weight of roots is observed on *gabbu-chinee*, *khatta*, sweet orange and *kichili* rootstocks than on the unworked seedlings of the respective varieties. These various instances would seem to show the various directions in which the scion probably operates in modifying the inherent rooting habit of the seedling rootstocks.

(5) A maximum depth of 320·00 cm. has been registered by a country orange seedling of about 38 months old, while in budded plants *gajanimma* rootstock has shown a maximum depth of 256·40 cm. with the scion of only about 21½ months of age. *Gajanimma* has also contributed the largest spread of roots both in unworked and budded plants with a maximum of 639·80 cm. and 543.30 cm. respectively.

(6) Sweet orange is marked out as the poorest both as a seedling and as a rootstock in regard to the depth and foraging power of the root system, although as a rootstock it appears to have definitely improved its rooting power. Since this variety has consistently produced the maximum percentage of fibre and proportionately greater root weight, it would seem that its apparently poor rooting habit cannot be considered as a disadvantage by itself, and that its inferiority seems to be mainly due to the relatively poor top growth during its initial period of life.

The above observations are of special interest in affording some surprising indications of the enormous foraging power of roots of certain citrus varieties. The vast difference in the root spread between the plants on various rootstocks as evidenced by the maximum spread of 543·30 cm. on *gajanimma* of about 21½ months of age after budding and the minimum of 246·20 cm. on sweet orange of about 23 months of age after budding serve to emphasize the value of determining the optimum orchard spacing for oranges of about the same age on different rootstocks. That the criterion for judging the suitability of a rootstock does not appear to lie solely on the depth or spread of its root system but also on the proportion of fibre and root weight relative to shoot weight is yet another fact of possible importance indicated from these various studies.

It would also appear from a perusal of the foregoing data that there is a wide difference in the root systems of *kichili* and country orange. This fact strengthens the popular belief that these two are distinct varieties.

Discussion

Of the various rootstocks used in the investigations reported herein, useful information on the relative performance of such rootstocks as sour orange, sweet orange and rough lemon under diverse conditions of growth and culture are already available in citrus literature. To a lesser extent, the adaptability rootstock effect and incompatibility of pummelo, acid lime and *C. tangerina* Hort. Tanaka as observed in certain countries have also been made available by the respective workers. A valuable summary of the salient points in these various rootstock trials has been prepared by Hatton [1932]. The rootstock trial with *chinee* orange scion discussed in this paper includes two other citrus rootstock species and one new strain of sweet orange. In neither of these cases, any work has been done so far in any part of the world. Since these have presumably originated as chance seedlings in this part of India and have been observed to withstand neglect and drought conditions to a remarkable degree in certain parts of the Ceded districts of Madras Province, it is considered useful to test their rootstock potentialities along with those of the well-known rootstocks in use elsewhere.

The soil of the plots in which the present investigations have been conducted being red loam of great depth, the inferences deduced and presented in this paper can but be of application only to similar conditions. It is necessary to bear this in view, especially while discussing the various facts that have emerged from the root studies and growth increment data.

The data collected on the percentage of apogamic seedlings produced by different varieties indicate that the strains of *jamberi*, *gajanimna*, *kichili* and acid lime used in these studies are highly polyembryonic, those of pummelo, *chinee* orange, and *mokri* are monoembryonic and those of *herale* and *gabbu-chinee* are slightly polyembryonic.

Since the present data are based on seedling counts and not on embryo counts, the above inferences can be only suggestive and not conclusive. As a matter of fact these inferences in respect of *chinee* and *mokri* are contrary to the findings of Webber [1931], who has determined the range in percentage of apogamic embryos in sweet oranges to be 40 to 95, and in citron 40 to 50. Webber has also found that sour orange is highly polyembryonic, accounting for 75 to 85 per cent of apogamic embryos. Quoting the findings of Torres who had worked with 50 seed samples in Philippines, Traub and Robinson [1937] have shown that the range of embryos per seed varies from 1 to 12 in sweet oranges, 1 to 6 in rough lemon, 1 to 3 in sour oranges and 1 to 2 in limes. Pummelo was the only variety that did not exhibit polyembryony. According to Torres, the average number of embryos per seed was the highest in sweet orange (4 88) and least in sour orange among the nine polyembryonic varieties tested. The data adduced by Webber and Torres, therefore, differ materially from each other in regard to the extent of polyembryony in sour oranges, while in respect of sweet orange, the data presented in this paper on

the basis of a study with 100 seed samples vary from those of either of these workers. In a separate trial with about eighty seeds of *chinee* orange, it was also found that not a single seed produced more than one seedling. Torres [1936] has also shown that the correlation between embryo counts is statistically insignificant, although he argues that the more embroys the seed contains the weaker they will be and the less their chance of successful germination. In the face of all these various findings, the only valid inference that is warranted is that the pummelo is definitely monoembroynic, and the apparently monoembryonic nature of *chinee* orange and *mokri* may perhaps be due either to the variation between the horticultural varieties of sweet orange and citron or to the effects wrought by environment in the tree or in seed beds.

With a variable material as that obtained from seedling rootstock, the first problem that confronts the worker initiating the field experiments with citrus is that of increasing the uniformity to the maximum extent possible. The system of roguing out of the variants and under-sized seedlings and selection of seedlings from the modal class as practised in these investigations has clearly narrowed down or restricted the variability in so far as the quantitative measurements of growth are concerned. It is to be seen if these measures will reduce the variability in respect of tree performance also in later years.

The proportion of seedlings in the modal class are found to be the largest in acid lime, *jamberi* and *kichili* and least in *gajanimma*. The under-sized and weak seedlings have formed the largest proportion in *gajanimma* and least in acid lime. On an analysis of the graded seedlings after transplantation from seed to nursery beds, it is however, found that *kichili* is the most variable. Since a large percentage of seedling variants had been separated out in the case of *gajanimma* and a very large percentage amounting to 43·34 of under-sized and weak seedlings had also been rouged out, it is obvious that high uniformity observed in the graded seedlings of this rootstock cannot be considered to afford a true index of its inherent variability. Similarly, the uniformity of *gabbu-chinee* as observed in the final batch of seedlings is due to the larger number of variants budded previously and also the high proportion (35·42 per cent) of under-sized and weak seedlings rogued out. On the other hand, in spite of the separation of a large number of vigorous variants and of 36·60 per cent of under-sized and weak seedlings in *kichili*, this variety has contributed to exhibit a very high variability in the finally graded batch of seedlings. In the case of acid limes, however, the proportion of vigorous variants and of weak and under-sized seedlings was relatively small, notwithtanding which fact it has exhibited very high uniformity in the finally graded batch of seedlings. These various facts would show that, of the seedling progenies under study, acid lime is the least variable and *kichili* the most variable of all.

Webber [1932] has recommended that the selection of seedlings in citrus nursery should include the discarding of smallest seedlings to the extent of about 25 per cent in the seed bed and roguing out of all variant seedlings irrespective of size just prior to the plantings up to an extent of about 5 per cent. In general, the process of roguing out of small and under-sized seedlings and of variants and a further selection of uniform budlings as adopted in these trials are in conformity with the recommendations of Webber and tend to impart the maximum uniformity in the budlings.

Both prior to the budding stage as well as till the time of planting, the *jamberi* rootstock has occupied the front rank in the matter of producing plant vigour. *Gajanimma* is on a par with *jamberi* in both the above-mentioned respects, which fact is also in consonance with the popular experience of the growers of this variety. Working with apple trees, Sax and Gowen [1923] have shown that under similar conditions, the trees show early and permanent differences in size, and these differences apparently depend upon variability of the seedling rootstocks. As to whether this early revelation of clear differences in growth and vigour of seedlings will furnish a clue to its later behaviour or performance in the orchard is a point of undoubted interest, which cannot be elucidated at the present stage of these trials.

It must, however, be mentioned that the rate of growth as well as the vigour is a factor likely to be influenced to a considerable extent by the individual parents within a variety. This is borne out from the differential pre-orchard performances of the sweet orange seedlings of two different parents.

From the point of the nurseryman and citrus grower who would naturally welcome a knowledge of certain easily discernible plant characters associated with several aspects of the nursery and orchard operation and performance, the data presented in the paper are likely to prove interesting. For instance, it has been brought out that height measurements of seedlings do not afford any reliable indication of the suitability of the seedlings to receive buds, as the latter feature is mainly governed by the stem-thickness of rootstocks. Similarly, the rate of growth as observed in any particular period does not furnish a reliable clue to the ultimate vigour or size of the plant, as the rate of growth has been found in the case of *chinee* seedling during the pre-orchard life to be even more than the more vigorous *jamberi*. With regard to the 'take' of buds also, no reliable method is furnished from the data presented herein of determining the suitability of the varieties on the basis of their growth or vigour, as the varieties that have produced the maximum 'take' neither belong to the most vigorous nor to the least vigorous class.

It is observed that *billi-kichili* and pummelo have produced very high 'take' of sweet orange buds at one time and a relatively small 'take' at a later stage, while *gabbu-chinee* has produced the least at both times. Since these results have been obtained only during certain seasons, and since there is likely to be some variation in the optimum period for bud-insertion between varieties, these results of bud 'take' are not intended to furnish a correct index. It is also possible that the period taken to reach the optimum stage for bud 'take' may differ to a certain extent between varieties. Evidence in support of this assumption is afforded from the fact that *mokri* which is usually considered to produce a very high 'take' in North India has not produced similar result in the present trials. These various points seem to indicate the fact that the optimum season for budding is not the same for all varieties in all tracts and in all seasons.

The differential 'take' of buds with acid lime and sweet orange scion varieties particularly on *kichili* rootstock has been clearly brought out from these investigations. This has already been shown to establish the fairly well-understood phenomenon that different scion varieties respond differently to a given rootstock.

The merits of a given rootstock has to be judged not only on the basis of vigour and yield but also on its susceptibility to diseases and pests and on the extent of its compatibility with the scion variety. Although evidence has not been presented in the foregoing pages on the former factor, field observations have, however, revealed that *gajanimma* is the most susceptible of all the rootstocks to gummosis and pummelo and acid limes probably to withertip and canker respectively. Regarding the compatibility it is too premature to deduce any inferences, although the slight differences between the rootstock and scion-stem girth measurements seem to afford some preliminary indications of partial incompatibility. With the collection of such measurements in future years it is expected that a more definite idea would become available.

It is recognised that the number of individuals excavated in each variety for the purpose of root studies are limited and, therefore, definite inferences are not warranted on the basis of the data gathered from these investigations. It has to be remembered, however, that in an investigation of this type, practical difficulties in the way of handling large populations within a reasonably short period are enormous, which fact also rules out the observance of identical conditions for the conduct of these studies. It is on these grounds that the extensive literature comprising results often based on the studies of root systems of a single individual can be justified. A further evidence in support of the justification of these studies of root systems and of the inferences drawn therefrom are afforded by the findings of Swarbrick and Roberts [1928] that trees budded on the stems of seedlings have roots which are typical of the different seedlings.

Apart from the several interesting peculiarities of the varieties in regard to their root habits, certain valuable observations and inferences of practical value have emerged from these studies. The correlation between the success in transplantation of seedlings and the abundance of fibre in the upper soil layer or the existence of shallow scaffolding laterals is one such information to guide the growers in determining the optimum period of transplantation. If the varieties with low proportion of fibre in upper soil layers are transplanted in early stages, the chances of higher mortality of seedlings are necessarily great. On the other hand, the same seedlings if allowed to remain in seed beds for a longer period to produce more fibre or shallow laterals the success in transplantation becomes greater.

The enormous foraging power of roots of certain varieties as evidenced by the maximum depth of 189 8 cm. of about a ten-months-old *gabbu-chinee* seedling and of 320·00 cm. of a 38-months-old seedling of country orange and of 256·40 cm. of a budded orange plant on *gajanimma* after about 21½ months of bud-insertion are sufficient to show the enormous area covered by the citrus roots in soils of fairly open texture. This fact is further brought out from the data relating to the spread of roots, which in the *gajanimma* seedling referred to above had reached the maximum of 639·80 cm. and in the budded plant on the same rootstock to 543·30 cm.

The above observations are not exactly in accord in some important respects with those made by other workers elsewhere. Waynick and Webber [1930] have stated that in North America about 90 per cent of the active rooting area of citrus is in the upper 48 in. of the soil. West [1934] in Australia

has, on the other hand, found that the greatest concentration of roots of citrus on rough lemon rootstock was at 30 to 50 cm. from the soil surface. Allwright [1935] has judged that in a 14 year old Washington Naval orange plantation, three-quarters of the roots of the trees were in the top two feet and very few deeper than three feet. Gregory [1935] in Trinidad has found that the majority of the feeding roots in three year old Marsh grapefruit trees were at a distance of 3-18 in. from the trunk. In the same study, Gregory has shown that the lateral spread of manured trees exceeds the average spread of the branches, which was 42 in. He therefore proceeds to suggest that the fertilizers should be spread evenly over a wide circle starting 3 in. from the trunk. On the basis of other published works, Gandhi [1939] has also pointed out that the roots of citrus are capable of extending to a distance of two to three times the spread of branches. The data presented in this paper clearly suggest that tree spread is not a reliable index of the feeding area of the roots, which, though depending on the variety of rootstock, nevertheless covers a very much larger orchard space than that actually encompassed by the top-growth. That the spread of apple roots in sandy soils is twice to three times as far as the branches has also been pointed out by Rogers [1934], and Rogers and Vyvyan [1934], who have consequently emphasized the necessity for manuring well beyond the spread of the branches. Cultivating only in a small circle round the tree and application of manures in a limited space have also been pointed by Susa [1934] to be responsible for restricting the absorbing root area. Provision of small basins of two to three feet wide around the tree trunk for application of water and fertilizers, as is usually done in the young citrus plantations in this tract is, therefore, hardly sufficient to give the full benefit of these treatments to the growing tree. Nor will the determination of proper spacing merely on the basis of spread of branches will prevent root interlacing and the consequent competition between adjoining trees for soil moisture and nutrients. A definite alteration in citrus cultural practices, especially in the matter of spacing of trees, application of water and fertilizers, are therefore indicated under similar soil conditions as those employed in the present investigations.

On a consideration of all the relevant characters as brought out from the present studies of the pre-orchard life of the various rootstocks, it would seem that *jamberi* is the most suitable rootstock for *chinee* orange and acid lime. This variety has produced the highest germination, largest number of apogamic seedlings, a very high proportion of vigorous variants ready for budding within a year from sowing, a very large proportion of seedlings in the modal class and a very high ' take ' of orange and acid lime buds in different seasons. The seedlings also transplant well and make a good stand in nursery beds. The root system is well distributed, possessing an abundant fibre and good depth. The scions also grow very vigorously during the pre-orchard life. Furthermore, the variety has not shown signs of susceptibility to any of the more important citrus diseases. *Gajanimma* though has shown to be a virgorous rootstock suffers from such serious defects as poor germination, relatively low proportion of seedlings in the modal class indicating high variability and a high susceptibility to gummosis. Pummelo, being monoembryonic, cannot possibly find favour as a rootstock. It has further produced varying percentages of ' take ' with scion buds and is possibly susceptible to withertip disease. The varying ' take ' of buds on *billi-kichili*, poor

transplanting and the low proportion of vigorous seedlings variants are the defects which rule out this variety from the class of suitable rootstocks. Low percentage of apogamic seedlings and varying ' take ' of scion buds are defects in *mokri*, while *gabbu-chinee* merits no consideration, because of its poor ' take ' of both orange and acid lime buds, relatively low production of apogamic seedlings and poor transplanting habit possibly due to its bare root system in early stages. The production of abnormally deep root system in seedlings of this variety is, however, a character of some value, which deserves to be exploited. *Chinee* orange is very slow in growth both before and after working, besides producing a poor germination and its non or low production of apogamic seedlings. Its relatively higher weight of root relative to top growth, easy transplantation and well-balanced root system are, however, points that require to be considered in its favour. *Kichili* has shown a poor ' take ' with acid lime scion and has also not produced a very high germination of seeds or a high uniformity in seedlings. It has also sparse fibre in the root system in early stages. But for these few defects and possibly its relatively slow growth in the beginning, this rootstock can well be classed as one among the desirable. The data relating to *herale* is not comprehensive enough, even though its defects in the matter of poor germination and low percentage of apogamic seedlings have been brought out. Acid lime has been found to be susceptible to canker and to be not so easy for transplantation as the *jamberi* nor as efficient in producing vigour in the budlings. In other respects, it obviously possesses most of the favourable characters of a good rootstock.

The foregoing evaluation of the rootstocks cannot possibly furnish any clue to their future orchard performance. Nevertheless, the information presented in this paper is essential for a complete understanding of the problem of rootstock-scion relationship in cultivated citrus. It is on these grounds that the author ventures to present these results to the citrus-growing public and the research workers in this field.

Summary

(1) *Jamberi* has uniformly produced the highest germination in seed bed and is closely followed by pummelo, while *chinee* orange, *herale* and *gajanimma* have been found to produce relatively poor germination.

(2) The percentage of apogamic seedlings actually obtained in seed beds has been found to be the largest in *jamberi*, *gajanimma*, *kichili* and acid lime, while it was relatively low in *herale* and *gabbu-chinee*. Pummelo has proved to be distinctly monoembryonic.

(3) The proportion of vigorous growing variants that becomes available for budding within a year after sowing is found to be the largest in *jamberi*, *gajanimma*, *mokri* and *kichili* and relatively small in *chinee* orange, *billi-kichili*, *gabbu-chinee* and acid lime. For expediting the production of budded citrus plants, *jamberi* and *gajanimma* appear to furnish the most suitable material.

(4) Within a year after sowing, the size of seedling rootstocks as judged by their height and stem diameter measurements has been found to be the largest in *jamberi* and *gajanimma* and least in *chinee* orange and *billi-kichili*.

(5) The height measurements of the plants, do not seem to afford a reliable index of the suitability of the seedling rootstocks to receive buds.

(6) The rate of growth in seed beds appears to be influenced to a considerable extent by the individual parent and not the variety or the species.

(7) The differential ' take ' of buds on *billi-kichili* when worked at two different periods of growth establishes the fact that the optimum period for bud-insertion varies with the different rootstocks, and may also vary in different tracts and seasons.

(8) *Jamberi* and *gajanimma*, have produced invariably very high ' take ' of buds while *gabbu-chinee* has shown relatively low bud ' take '.

(9) Different scion varieties are found to respond differently on a given rootstock variety in regard to bud ' take ' ; and acid limes in general have contributed to a lower ' take ' of buds than the *chinee* orange scion.

(10) Acid lime has proved to be the least variable and *kichili* the most variable of the rootstocks under study.

(11) The repeated selection of plants has been found to be efficacious in restricting the variability of citrus seedling rootstocks.

(12) Although no definite idea about the rootstock-scion compatibility has been revealed from the data, it is however indicated that, pummelo and *gajanimma* have produced relatively larger rootstock stem thickness than those of scion stems, while *chinee* has produced the narrowest margin between these two measurements.

(13) With *chinee* scion, *jamberi* has registered the highest growth increments from seedling to planting stage and has also produced the largest sized plants at the commencement of orchard life.

(14) Although *chinee* seedlings were the lowest sized at the time of planting, they have recorded larger girth increment during pre-orchard life, possibly because of the fact that the inhibitive effect of bud-insertion has been non-operating in its case.

(15) During pre-orchard life, pummelo *billi-kichili* and acid lime have produced least growth increments.

(16) *Gajanimma* as a rootstock is on a par with *jamberi* in respect of contribution to scion vigour at the commencement of orchard life.

(17) With acid lime scion also, *jamberi* has produced the largest stem thickness, while acid lime the least at the time of planting.

(18) Notwithstanding the fact that individuals within a variety possess root systems of widely differing characteristics, certain specific or varietal characters have been brought out from the root studies and presented in the foregoing pages.

(19) The enormous depth to which the seedling root penetrates at a very early stage of its life has been emphasized and the enormous extent of root-pruning done at the time of transplantation indicated.

(20) Success in transplanting of seedlings has been shown to be dependent on the character of the root system. An abundance of fibre in upper soil layers or of shallow scaffolding laterals have been pointed out to be favourable for ensuring a good stand.

(21) From a consideration of the root systems of worked and unworked seedlings, the possible directions in which the scion modifies be rooting habits of the seedling rootstock has been indicated.

(22) That the merits of a seedling rootstock cannot be judged solely on the depth and foraging power of root system but should also be based on the proportion of fibre and of root-weight are points that have been made clear from the present studies.

(23) The enormous variation in the area combed by the root systems of different varieties when grown as seedlings or as rootstocks even at a very early stage of the plant life, as well as the vast extent covered by the roots at such an early stage, serve to emphasize the necessity of determining separately the optimum orchard spacing for *chinee* orange worked on different rootstocks on the basis of root studies. These also indicate that the popular practice of applying irrigation water and fertilizers in a small area around the plant is not adequate to meet the entire needs of the plant concerned.

Acknowledgement

The present investigations form a part of the programme of work of the fruit research scheme financed by the Imperial Council of Agricultural Research. A number of assistants have helped in the raising of the plant material, establishment of the experimental plantations and collecting the data. Of these, the assistance of Messrs M. Jeevan Rao, C. Bhujanga Rao and K. Rajabapanaiah deserve special mention. Sri. S. N. Venkatraman's help in suggesting the analysis and presentation of a part of the data is also gratefully acknowledged.

REFERENCES

Allwright, W. J. (1935). *Citrus Grower*, No. **40**, 24-39
El. Sawy, A. (1936). *Hort. Sect. Egypt* **50**, 5
Gandhi, S. R. (1939). *Trop. Agric. Ceylon* **92**, 3-15
Gregory, E. J. (1935). *Trop. Agric. Trini.* **12**
Hatton, R. G. (1932). *Impr. Bur. Fr. Prod. Tech. Commun.*
Hodgson, R. W. (1937). *Publi. Minist. Agric. Egypt* **15**
Pope, W. T. (1934). *Bull. Hawaii Agric. Expt. Sta.* **71**, 37
Rogers, W. S. (1934). *Sci. J. R. Coll. Sci.* **4**, 120-9, *Hort. Abst.* (1934), IV, Sept.
Rogers, W. S. and Vyvyan, M. C. (1934). *J. Pomo.* **12**, 11-44
Sax, Karl and Gowen, John W. (1923). *Main Agric. Exp. Sta. Bull.* **310**
Susa, T. (1934). *Jap. Min. Agric. Lit. Agri. Improvements* **81**, (*Hort. Abst.* IV, **4**, Dec. 1934)
Swarbrick, T. and Roberts, R. H. (1928) *Biol. Absts.* **2**, 6-8, 12491
Tanaka Tyozaburo, (1937). *J. Ind. Bot. Soc.* **16**, 227-40
Torres, J. P. (1936). *Philip. J. Agric.* **7**, 37-58
Traub, H. P. and Robinson, T. R. (1937). *Yearbook Agric. U. S. Dept. Agric.*, R 794
Waynick, D. D. and Walker, S. J. (1930). *Calif. Citrograph* **15**, 201-38
Webber, H. J. (1931). *Proc. Amer. Soc. Hort. Sci.* **28**, 53-61
———————— (1932). *Hilgardia* **7**, 1-79
West, E. S. (1934). *J. Coun. Sci. Indust. Res. Aust.* **7**, 87-93

A REMARKABLE WILD HOST PLANT OF THE COTTON STEM WEEVIL, *PEMPHERES AFFINIS* FST., FROM SOUTH INDIA, AND ITS PARASITIC ASSOCIATES

BY

P. N. KRISHNA AYYAR

Parasitologist, Agricultural College, Coimbatore

(Received for publication on 18 May 1938)

(With Plates XXII-XXVII)

INTRODUCTION

THE alternate food plants of *Pempheres affinis* have recently been receiving some attention primarily with the object of finding any new and promising parasites. Investigation prior to the inception of the present studies had largely tended to discount the importance of this aspect of study. This is evident from a statement in one of the latest publications on the subject [Dharmarajalu, 1934] namely, that the ' insect is unable to breed, leaving a few *Corchorus* plants, on any plant other than cotton.' Data in support of this conclusion were, however, lacking. On the other hand, an earlier publication [Ballard, 1922] has furnished a fair number of plants under the head. In the face of these conflicting opinions, a systematic survey though limited to the immediate neighbourhood of Coimbatore was carried out for very nearly a year. In the course of such a survey, numerous cultivated plants and weeds growing in and around cotton fields have been repeatedly examined month after month and the data gathered served to bring to light a large number of food plants. Many of the plants noted, freely admit of profuse breeding of the weevil and a few constituted new records. The infestations in some were so heavy, varied and widespread* that the problem gradually acquired a new interest. The search was therefore recently extended to a few adjoining localities including a few hill tracts and forest areas far away from cotton cultivation. This extended survey has resulted in bringing into prominence, among others, one particular species of food plant, namely, *Triumfetta rhomboidea* which forms the subject of this short paper. This species has revealed a phenomenally high percentage of weevil infestation and parasitism. Though *Triumfetta* sp. has been previously listed among food plants [Fletcher, 1919; Ballard, 1922], the species *rhomboidea* was for the first time observed by the writer to harbour this weevil during January 1937 when a small collection was made in Telugupalayam in the vicinity of Coimbatore.

The plant and its distribution

Triumfetta rhomboidea Jacq.—Tiliaceae (Tamil *adai otti*, Hindi *chikti*, Plate XXII) is a common herbaceus undershrub widely distributed in the

* A comprehensive account of all such plants is reserved for a future publication when matter becomes ripe for the same.

hills and plains throughout the tropical and sub-tropical India from the Himalayas to Cape Comorin ranging up to an elevation of 4,000 feet. In this province it enjoys a fairly even distribution in all the districts as seen from the collections in the herbarium.* The plants generally lie scattered among a varied vegetation and occur in very diversified situations. The species has been noted to be a common inhabitant of uncultivated waste places, weed areas near villages, along river and canal banks, outskirts of coconut and arecanut topes, borders of fields, fencings of gardens and compounds, roadsides and extends to forest regions and hill slopes. It seldom grows over three or four feet in height and has been taken from all localities in the vicinity of Coimbatore within a radius of seven or eight miles, such as Telugupalayam, Vedapatti, Vadavalli, Perur, Mathampatty, Chittraichavadi, Kuniammuthur, Singanellore, Thondamuthur, etc. Large collections have been occasionally made from distant places like Irittupallam, Siruvani hills, Thadagam and Dhoomanur, Kallar, Wallayar and Dhone valley (Malabar). The species cannot be considered to be of any great economic importance. Previous literature lists *Triumfetta* sp. among alternate food plants. But no data of any kind in regard to the exact species, locality, nature and extent of infestation or its parasitic fauna are available. Such data are highly important and necessary, particularly because another common species of the genus, namely, *T. rotundifolia* even more widely distributed and abundantly met with everywhere, on repeated examination, has been found to be singularly free from infestations.

Mode of attack and nature of habitat

Pempheres infestation in this plant has been repeatedly observed to be so severe that there seems to be ample justification in considering it as the most favourite food plant. The nature of the plant and the nutrition afforded largely determine its attractiveness to the insect besides having an important bearing on its development and multiplication. The attack here is not restricted, as in other plants like cotton, to any particular parts of the plant like the hypocotyl region but is more or less uniformly distributed throughout all portions of the herb from the upper portions of the roots, along all regions of the stem extending to even secondary branches with the exception of very slender ones lacking in the requisite minimum thickness (say less than 2 mm.). No doubt the age and size of the plant and the nature and thickness of the stem, to some extent, govern the heaviness of infestation. It is generally the older plants that are more heavily attacked, the younger ones showing comparatively lighter infestations. In these plants, particularly older ones, numerous stages representing every developmental instar are met with simultaneously, demonstrating that the plant is acceptable as food for successive generations. It also shows that considerable overlapping of broods takes place and heavy populations are rapidly built up by continuous multiplication. The density of population in the species seems to grow until its maximum capacity is overreached and the plant is killed by sheer abundance of attacks. Though apparently there is a general similarity in the method of

*The writer is indebted to the Systematic Botanist's section for the identification of this and several other species.

attack in this species and cotton, a few marked divergences in some particulars may be noted. Some minor deviations may be noted even in the matter of oviposition. The eggs are not much sunk in the bark but are nearer the surface than in the case of cotton, probably due to the fact that the bark here is comparatively much thinner. The newly hatched minute grub first mines encircling the stem or branch for a short while but quickly migrates into the deeper woody tissue and consistently resides and tunnels in the central pith region where it eventually transforms itself into a prepupa and pupa. This is greatly facilitated by the somewhat succulent and fleshy character of the woody tissue as well as the comparative softness of the stem which is pithy though not hollow. The food value and nutrition afforded appear to be extremely conducive as evidenced by the healthy and robust nature and large sizes of several instars. The grubs are creamy white, robust, and active with strong dark brown mandibles. The prepupae and pupae are proportionately bulkier. The adults developed appear to be giants in comparison with those in cotton or other food plants and are occasionally a shade darker. Oviposition also seems to be profuse as seen from a few trials. The mechanical damage caused to the host plant is certainly greater but the repair and recuperation effected by the plant is quicker as seen from the numerous large-sized galls developed in all parts of the plant including branches. That the weevil develops successfully and emerges with ease may be evident from the fact that the stem and branches are literally covered and riddled with conspicuous and large adult emergence apertures. As large a number as 127 galls and 180 emergence apertures has been recorded on a single plant in September 1937.

Comparison with other food plants

The weevil has been observed during the present investigation to breed in a number of other plants such as *Sida acuta*, *Sida rhombifolia*, *Sida glutinosa*, *Corchrus olitorius*, *Urena lobata*, *Hibiscus vitifolius*, *Malvastrum coromandelianum*. Cultivated plants include *H. esculentus*, *H. cannabinus*, and *Althaea rosea*. In none of these including its primary host, cotton, has the insect been noted to increase to the extent usually found in *T. rhomboidea*. Among these a species of *Sida* requires special mention. *Sida acuta* occurs often in similar situations and associations as *T. rhomboidea* and is comparatively widespread. There is considerable similarity between the two species in the mode of attack and course of tunnelling in that the stages are met with in the greater portion of the stem and migrate into the central region of the stem, but it cannot stand comparison with *T. rhomboidea* either in degree of infestation, hugeness of population, in the sizes of stages or in the extent of parasitism. The plant is much more woody and hard and the stages do not find it suitable for growth and emergence. Either the attack is less severe or enormous mortality and elimination of stages occur in this host. Galls are rarely developed and emergence apertures much fewer. The grubs are very often lean, discoloured being pinkish or dusky and a proportion inclusive of adults is found dead *in situ* apparently unable to emerge. In point of size of stages the only other plant that nearly approaches *T. rhomboidea* is *H. cannabinus* but the percentage of attack in this case is very low.

Ecological features of the habitat

With the present knowledge based on a limited survey of its distribution and infestation, a comprehensive discussion of the environmental characteristics of the habitat cannot be attempted. The infestation has been no doubt observed in a fairly wide range of situations and a variety of conditions. It has been noted though in varying degrees, alike in places with moderate rainfall like Coimbatore and suburbs and others with excessive rainfall such as Wallayar and Dhone valley in Malabar. It occurs also in great elevations like Siruvani and Mankarai. In drier tracts, infestations are confined to shady, damp localities along water courses or similar moist situations. One general observation that emerges from the studies is that moisture plays an important part in the occurrence and abundance of the weevil infestations, whatever may be the divergences in other features climatic, physical or biological.

Intensity of infestations

Observations recorded for the last ten months from a variety of localities serve to illustrate the extent of infestation, population densities and seasonal variations. It is never evenly or uniformly distributed in all localities. Much variation occurs even in plants taken from different situations in the same locality. Striking differences exist in plants from the same situation in accordance with variation in age and size of the plants. The general rate of infestation for the past ten months oscillated between 42 and 100 per cent averaging about 77 per cent for the entire period. Places like Thondamuthur and Irittupallam have shown consistently high percentage in infestations as well as parasitism. More striking are the data obtained regarding the populations for a locality or for an individual plant. From data recorded for the last two years for cotton, the average population has seldom risen over four or five per plant even in heavily infested fields. Whereas *T. rhomboidea* has often displayed as high a number as ten or more individuals per plant. Judging from the egg-laying capacity of the weevil (a maximum of

TABLE I

Months (1937)	No. of plants examined	Total number of infestations	Per cent infestations	Weevil population per 100 plants
January	12	84	50	525
February	4	88	100	1,000
March	31	251	42	245
April	13	134	100	385
May	6	61	100	483
June	6	26	83	50
July	41	241	56	229
August	29	416	69	917
September	36	841	92	1,017
October	27	687	77	748

121 per female) the biotic potential is not very high. Other environmental factors remaining constant any marked variations in the insect population, therefore, may be governed by the suitability of the host species. Weevil population data recorded for this plant, therefore, indicate a high preference for this plant species. Table I presents the percentage infestation and populations per 100 plants noted in Coimbatore and its environs for the last ten months.

All localities so far explored have shown appreciable infestation though the severity of attack varied in different localities. One of the reasons for such variations may be attributed to the relative abundance or scarcity and scattered nature of the distribution of the food plant. Localities like Dhone, Wallayar and Kallar where large patches of the plants are seen to occur in certain situations, showed that the populations get more evenly distributed. Table II below provides data in relation to different localities.

TABLE II

Locality	No. of plants examined	Total No. of infestations	Per cent of infestations	Weevil population per 100 plants	Remarks
Kuniamuthur	31	403	94	423	September 1937
Thondamuthur	28	623	82·5	606	
Mathampatty	9	819	66·7	2,078	
Alanthurai	19	240	68·0	226	
Siruvani	12	168	100·0	458	
Thadagam	25	122	86·0	652	February 1937
Dhone	15	45	100·0	93	
Kallar	65	31	16·9	21	November 1937
Irruttupallam	38	844	92·0	616	October 1937
Kuniamuthur	37	149	60·0	133	
Singanellore	7	119	100·0	657	
Thenamanur	12	486	100·0	1,333	
Thondamuthur	48	1,420	100·0	702	
Siruvani slope	7	125	100·0	529	
Siruvani uphill	17	24	41·0	37	
Dhone	412	424	17·0	27	
Wallayar	214	527	59·0	42	

The infestation in individual plants within the same locality or situation varied so greatly that a general average figure of percentage of attack or live population fails to convey any accurate idea of the capacity of this species to harbour heavy population. The following table presents data on the maximum number of infestations carried by individual plants during each of the past ten months. The composition and representative character of the live populations may also be noted from the table.

TABLE III

Months 1937	Maximum number of infestations in a single plant	Young grubs	Medium grubs	Mature grubs	Pre-pupae	Pupae	Adults	Maximum live population in a single plant	Remarks
January .	26	2	3	8	3	1	2	19	The collections were small. Search was not thorough and was confined to the immediate surroundings.
February .	49	1	3	13	...	3	...	20	
March . .	65	5	1	5	...	1	...	12	
April . .	22	6	...	2	...	3	...	11	
May . .	21	3	5	3	...	...	1	12	
July . .	46	6	5	3	...	2	4	20	
August . .	98	8	7	29	4	10	8	66	
September .	523	12	26	50	6	11	5	110	
October .	359	12	24	31	3	4	5	79	From 2 localities in the same month.
October .	342	11	39	41	3	2	...	96	

PARASITISM

This plant has provided the bulk of the weevil parasite material not collected in cotton. There are about seven species belonging to Braconidae and Chalcidoidea besides a parasitic nematode which definitely parasitize the weevil in this plant. The majority of these parasites (all except one species) are absent at present in cotton areas and constitute new records on *Pempheres*. All are primary in character and confine their attention to weevil larvae, particularly the mature grubs. In this connection, the absence of any species parasitizing the prepupae and pupae is keenly felt since such stages, being found in the deeper tissues of the stem and well protected, are little affected by other factors. Earlier stages such as eggs and grubs being very delicate and sensitive to desiccation are naturally eliminated to some extent by various ecological factors. No hyperparasites have so far been noted. There is one species among these which is endophagous. Some of these parasites seem to be efficient provided they can be successfully introduced in cotton areas. Their utility will depend upon their ability to establish, multiply and spread in the new habitat of cotton fields. This aspect of the problem is a new development and appears to be full of promise.

The rate of parasitism varied considerably in different regions. A maximum percentage parasitization of 14·5 for the entire area has been recorded but certain situations in the same locality showed a much higher rate. One plant for instance from Mathampatty having about 110 live stages yielded 27 parasites which works up to 25 per cent parasitism.

PARASITIC FAUNA

The following species have been noted to be parasitic on *Pempheres* in association with this food plant :—

Chalcidoidea

1. *Dinarmus coimbatorensis* Ferr.
2. *Entedon pempheridis* Ferr.
3. *Bruchocida orientalis* Crawf.

Braconidae

4. *Spathius labdacus* Nixon
5. *Spathius critolaus* Nixon
6. *Rhaconotus cleanthes* Nixon
7. *Rhaconotus menippus* Nixon

Among these, *Bruchocida orientalis* and *Rhaconotus menippus* may be considered as of very little importance, since each of these species has been encountered not more than once in association with this food plant, during the entire period covered by these studies. The following account, therefore, mainly centres round the remaining five species.

TABLE IV

Seasonal occurrence of the parasites

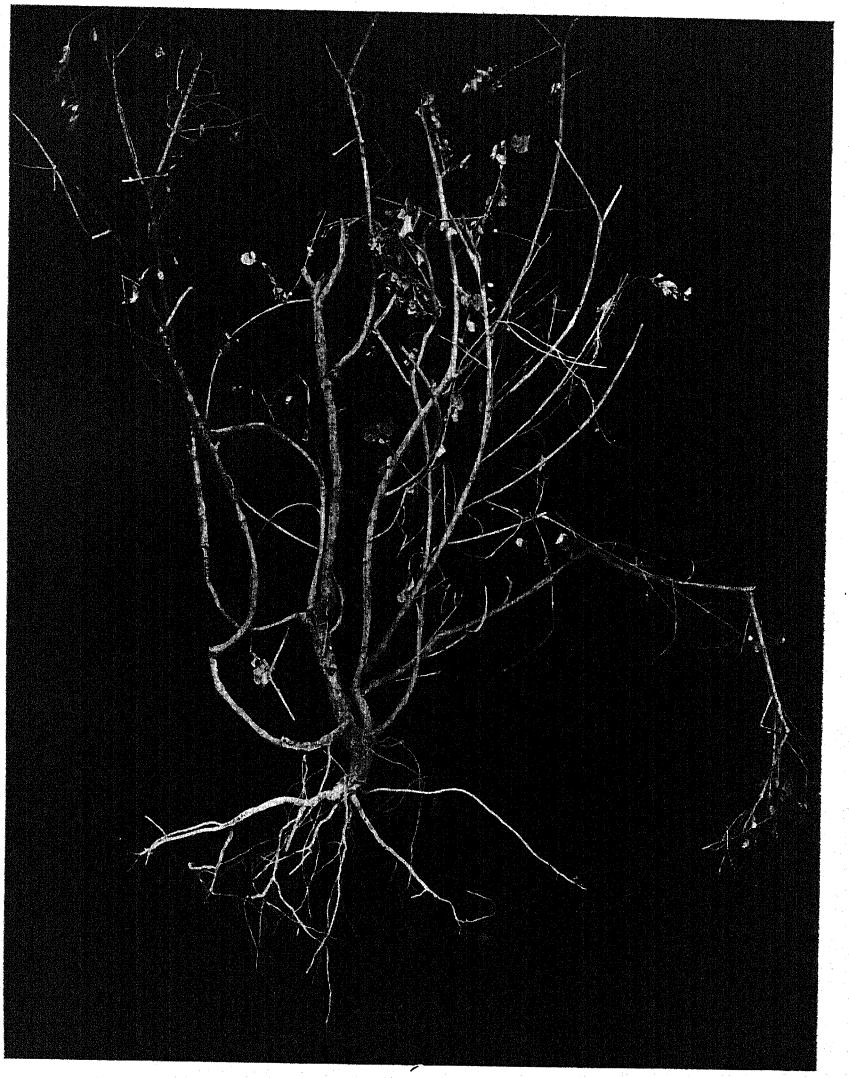
Parasite species	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1. *Dinarmus coimbatorensis* . .	2	2	...	7	5	8	14	11
2. *Entedon pempheridis* . . .	...	...	...	...	22	103	73	51
3. *Spathius labdacus* . . .	...	...	...	...	...	16	26	24
4. *Spathius critolaus* . . .	...	2	...	...	1	2	2	...
5. *Rhaconotus cleanthes* . . .	...	...	...	...	...	...	4	1

The degree of parasitism by any one of the species varies considerably in the different localities or in different situations in the same locality. The table above furnishes data on the proportion of the various species during the period from April to November 1937. Among these there is only one species namely *Spathius critolaus* that occurs in cotton fields. It has been also taken from other food plants like *Sida acuta*, *Corchorus olitorius*, and *Malvastrum*. *Dinarmus coimbatorensis* seems to be associated with a number of alternate food plants, having been recorded from *H. esculentus*, *Sida acuta*, *C. olitorius*, *H. ficulneus*, *H. vitifolius*, and *Malvastrum*. *Entedon pempheridis* has been recovered also from *C. olitorius* and *Sida acuta*. *Spathius labdacus* seems to be confined to only *T. rhomboidea*.

Dinarmus coimbatorensis Ferr. (Plate XXIII).—The adult female is a dark green, thickset Chalcid with an elongate abdomen varying in length from 2·5 mm. to 5 mm. and the male with a large yellow spot at base of abdomen varies in length from 1·5 mm. to 3 mm. Ferriere [1939] has recently described the species.

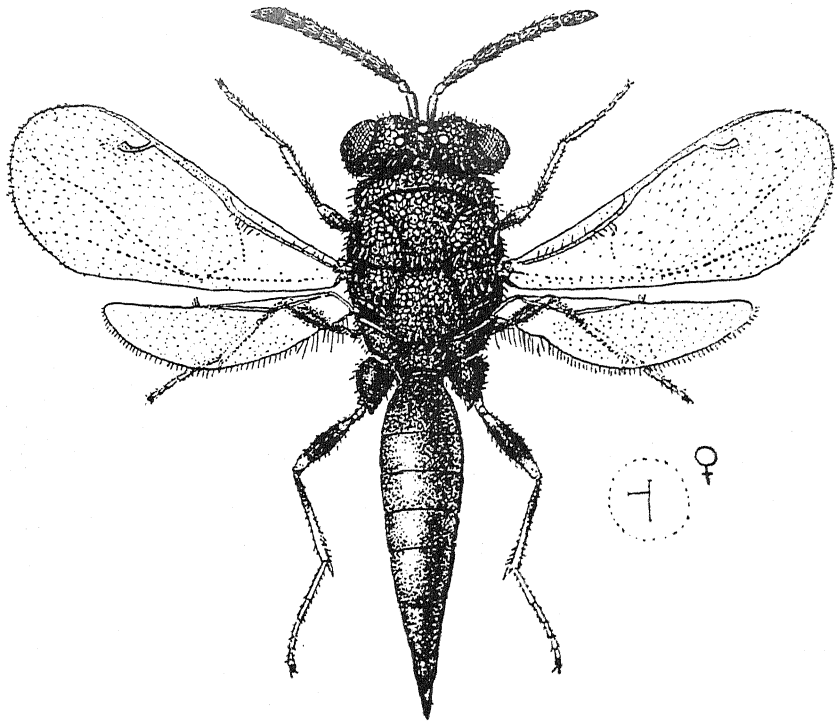
This species may be distinguished from all other known species by the combination of the following characters : the medially incised clypeus, the punctate propodeum without median carina, the brown ring at base of hind tibiae and the elongate abdomen.

This species is primary and ectophagous in character. It is a larval parasite with a partiality for full-grown host grubs. The parasite has since been successfully bred in the laboratory on *Pempheres* grubs provided in cotton stalks. It occasionally oviposits in captivity but is very slow and erratic in this regard. Eggs (Plate XXIII, fig. 2) are laid singly on any part of the host after partial or complete paralysation. In one case as many as six eggs were seen laid on a single host grub within an interval of 30 minutes by a female during mid-day. The egg measures about 0·6 mm. in length. It is somewhat oblong-ovate with one end feebly produced. The surface is uneven and has a sculptured appearance being covered by very minute spines. Partheno-genetic reproduction has been noted to occur in this species. The pre-oviposition period ranged from 4 to 35 days in captivity. The larva



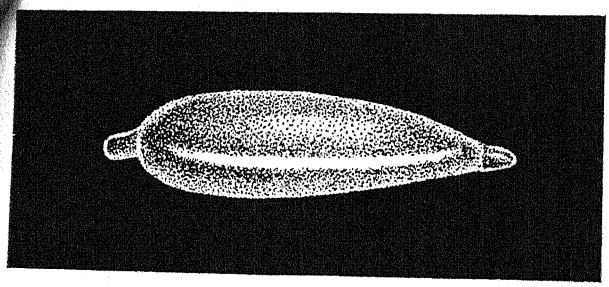
Triumfetta rhomboidea—typical heavily infested plant

Dinarmus coimbatorensis Ferr.



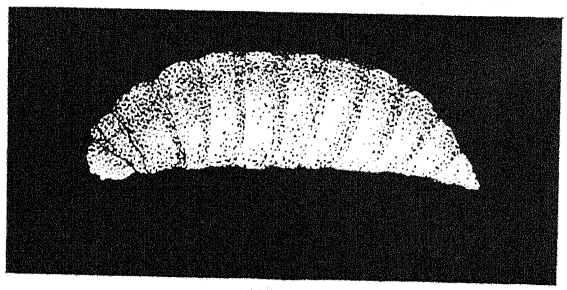
×12

FIG. 1. Adult female



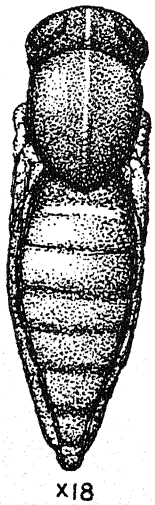
×85

FIG. 2. Egg



×18

FIG. 3. Full-grown larva



×18

FIG. 4. Pupa

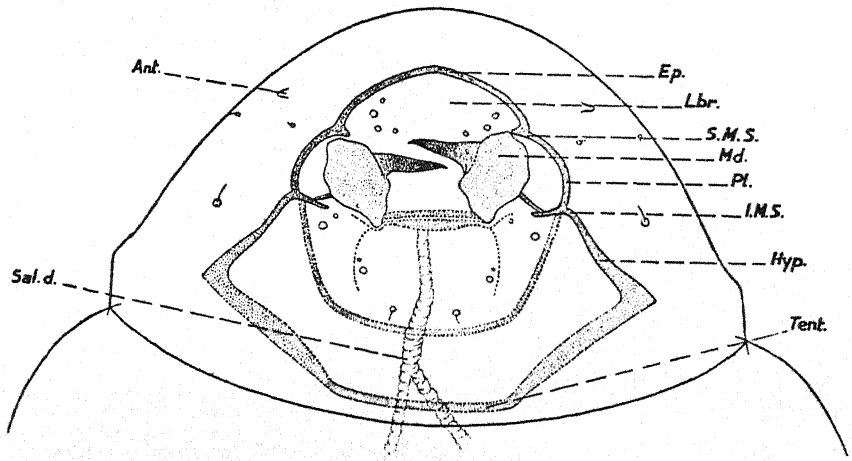


FIG. 5. Head and mouth-parts of full-grown larva

[Ant.=antenna; Ep.=epistoma; Hyp.=hypostoma; I.M.S.=inferior mandibular strut; Lbr.=labrum; Pl.=pleurostoma; S.M.S.=superior mandibular strut; Tent.=tentorium; Sal. d.=salivary duct]

completely consumes the host grub and assumes a robust rounded body with a distinct brownish head before it transforms into a prepupa (Plate XXIII, figs. 3, 4, 5). It has also been recovered from *Pempheres* infesting several other alternate food plants as also from *Hypolixus truncatulus* in amaranthus. It is absent from cotton fields. The life-cycle varies from 17 to 21 days made up of one or two days as egg, six to eight as larva, one to three days as prepupa and 10 to 10½ days as pupa. Adult longevity reached a maximum of 42 days averaging 23 days for four individuals with a daily supply of honey solution or raisin as food. In a proportion of cases, adults have been noted dead *in situ* in stems and pupae fail to develop into adults particularly in *Sida acuta*. The species has been collected from Malabar, Wallayar, Thadagam, Coimbatore and Siruvani. Since the species attacks *Pempheres* in cotton stalks in cages, there seems to be no reason why it should not establish itself in cotton fields.

Entedon pempheridis Ferr. (Plate XXIV).—This is a metallic blue and green Chalcidoid with an average length of 2·5 mm. ut varying from 1·5 mm. to 3·5 mm. in length. The species has been recently described by Ferriere [1939].

This species has been the most numerous among the parasites from alternate food plants. The species has been taken in small numbers occasionally from other plants like *C. olitorius*, *Malvastrum coromandelianum* and *Sida acuta*. It has been also noted to parasitize, to a small extent, other weevil grubs like *Apion* sp. in *C. olitorius*, *Lobotrachelus* in *Hibiscus manihot*. A single male specimen has been recovered from *Hypolixus truncatulus* in amaranthus. It is totally absent in cotton fields. It enjoys a wide distribution having been collected from Malabar, Wallayar, Thadagam, Siruvani and Coimbatore and suburbs. This is also a primary larval parasite. This seems to be the only endophagous parasite so far met with in *Pempheres*. The egg, larval and a portion of prepupal stages are spent inside a full-grown host grub. The host grub is not paralysed by oviposition. It seems to be apparently healthy, normal and unaffected, and tolerably active for a day or two until the parasite larva is hatched and begins to feed on the fluid contents of the body cavity in the initial stages. As the larva grows, it begins to feed on the internal organs and the activity of the host grubs gets more and more diminished. Probably only one egg is laid in each host as not more than one parasite larva has been noticed inside a single host stage and only one adult has been seen to develop from one host. The parasite larvae have been dissected out in a number of instances in varying stages of growth (Plate XXIV). These are milky white, flattened, leaf-like until they are full grown. When they get full grown the entire contents of the host grub are consumed leaving only a thin cuticular sac-like covering. The larva grows rapidly and assumes a robust cylindrical form filling up the cuticular bag and causing it to bulge out due to pressure of the growing parasite from inside. As it develops into a prepupa, the distended and weakened cuticular covering is unable to retain it, gets dry, cracks and crumbles leaving the parasite exposed. The parasite soon pupates naked and assumes a jet black colour No trace of the host may be seen except the small hard mandibular remains. The pupal period ranges from 8 to 12 days averaging 11 days for about 40

individuals. The egg has not been noted except in a doubtful instance. The entire development has been accomplished in captivity. The duration of egg and larval period has not been accurately determined but from a few observations it may be said roughly to vary from 8 to 11 days. The egg period lasts probably only for a day. The prepupal period may extend to even three days. The adults are strongly heliotropic being found to crowd towards the end of the tube directed to sunlight. Adult longevity with raisin as food has risen up to 18 days. The extent of parasitism by the species is seen to be the highest and the parasite appears to possess considerable possibilities if only it would accommodate itself in cotton fields. As large a number as 103 individuals (consisting of 9 adults, 93 pupae and one full-grown larva) were obtained from this food plant in September 1937. A maximum number of 11 parasites has been recovered from one single plant.

Bruchocida orientalis Crawford.—There is only one solitary instance when this species was collected. This was recovered as a pupa from a mature grub of *Pempheres* in *Triumfetta rhomboidea* in Perur on 7th July 1937. This emerged as an adult female on 12 July, 1937. The adult was comparatively large sized with a dark head and metallic blue and green body. The ovipositor was fairly conspicuous with a yellow brown colour and dark tip. The female lived in captivity for a period of 21 days with a supply of sugar solution. It also paralysed about seven *Pempheres* grubs provided in cages but failed to oviposit. It has been recorded as parasitic on *Bruchus chinensis* from Bangalore.

Spathius critolaus Nixon.—This is a slender elongate reddish brown insect about 2 to 3 mm. in length with a dark abdomen and vestigial wings. Winged forms are occasionally found to occur in both the sexes but more often among females. This is a common parasite which has been recovered in association with most food plants, including cotton. It is an ectophagous larval parasite attacking mature grubs and rarely medium sized ones also. It lends itself to breeding and multiplication in captivity not only on *Pempheres* but also on such subsidiary hosts like Amaranthus weevil grubs, *Hypolixus truncatulus* and the Bostrychid borer of cotton—*Sinoxylon sudanicum*. Normally eggs are laid singly one on each host grub, after complete paralysation of the same by stinging. A maximum of 53 eggs has been recorded for a single female. It displays considerable discrimination in selecting its victims preferring healthy, active, non-parasitised host grubs. The percentage of parasitism in nature has seldom risen above one per cent in cotton fields in the most favourable season, but it paralyses more host grubs than actually oviposited upon. The total life-cycle period varies greatly according to season from a minimum of 12 days to 28 days in cooler months. The parasite enjoys a wide distribution occurring as it does in cotton and non-cotton areas such as Ramanad, Erode, Coimbatore and suburbs, Thadagam, Siruvani and Malabar.

Spathius labdacus Nixon (Plate XXV).—This is a fairly large Braconid varying very much in colour and size. All grades of colour from reddish brown to dark brown are met with. In length it varies from 3 mm. to 4·4 mm., averaging about 3·7 mm. for a dozen specimens. The species has been described by Nixon [1939].

ENTEDON PEMPHERIDIS FERR.

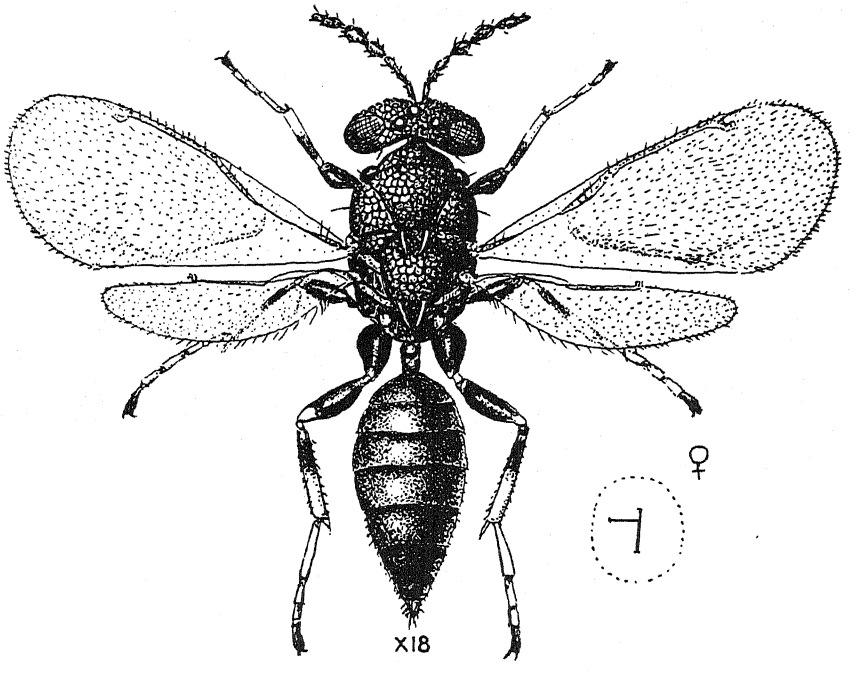


FIG. 1. Adult female

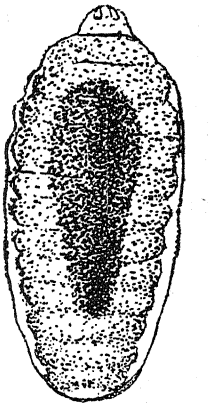


FIG. 2. Ist stage larva (dorsal view)

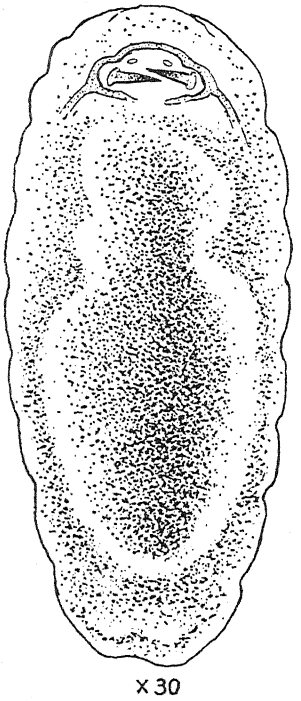


FIG. 3. Medium-sized larva (ventral view)

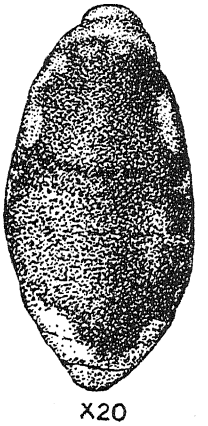


FIG. 4. Full-grown larva (dorsal view)



FIG. 5. Pupa (ventral view)

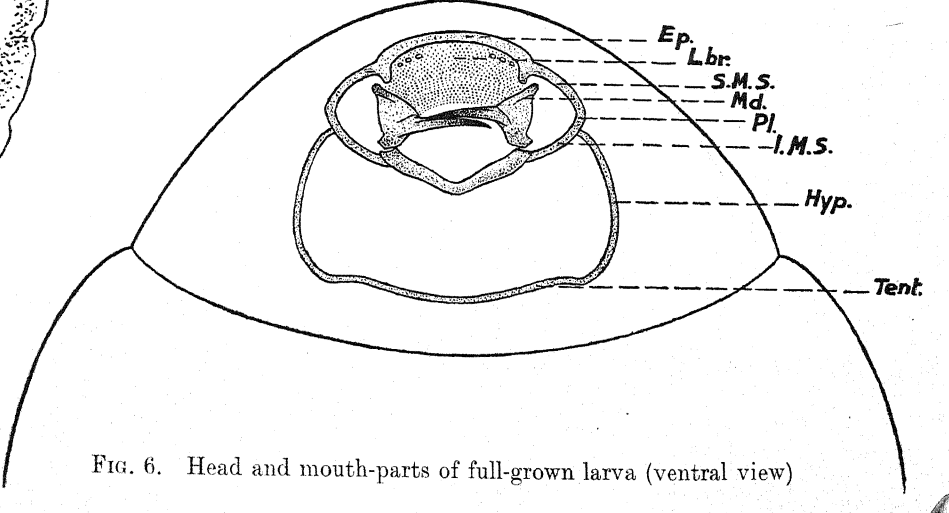


FIG. 6. Head and mouth-parts of full-grown larva (ventral view)

[Ep.=epistoma; Hyp.=hypostoma; I.M.S.=inferior mandibular strut; Lbr.=labrum; Pl.=pleurostoma;

SPATHIUS LABDACUS NIXON

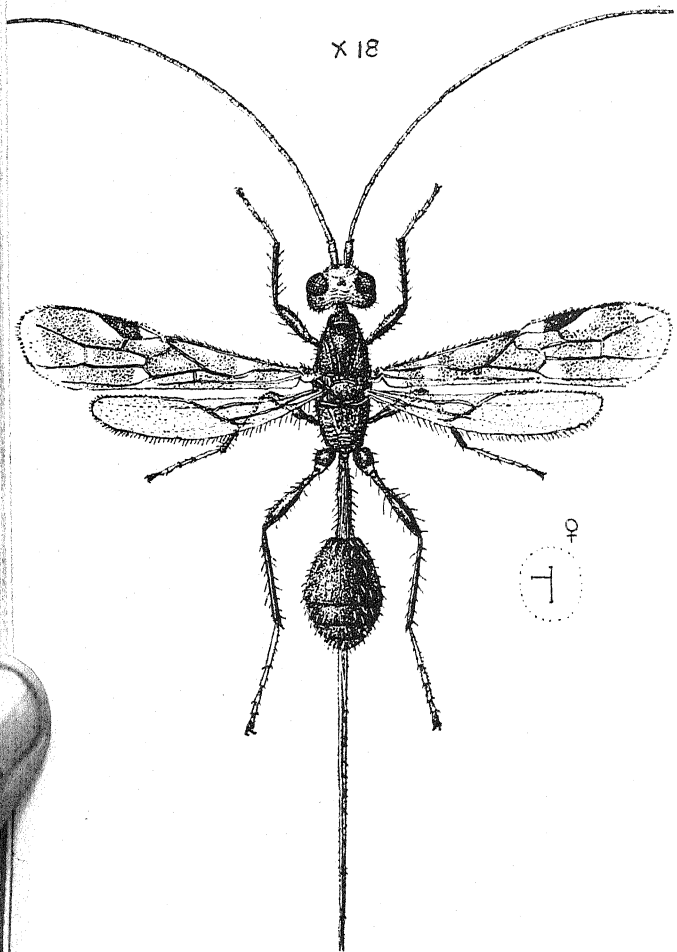


FIG. 1. Adult female

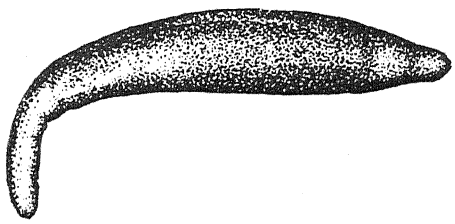


FIG. 2. Egg (magnified)

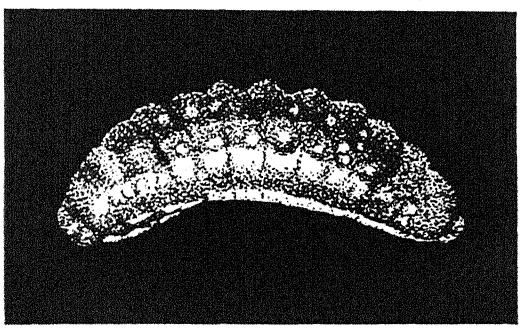


FIG. 3. Full-grown larva (side view)

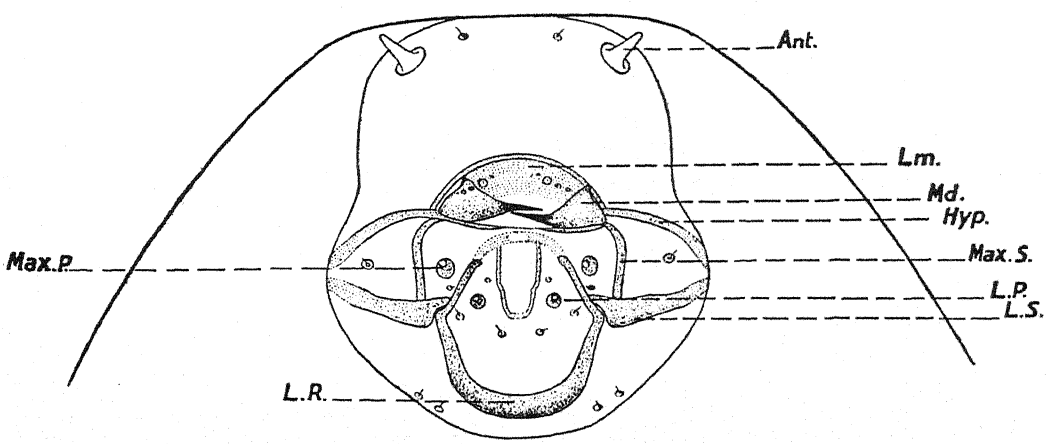


FIG. 4. Head and mouth-parts of full-grown larva

[Ant.=antenna; Lm.=labrum; Md.=mandible; Hyp.=hypostoma; Max. S.=maxillary strut; L.S.=labial strut; L.R.=labial ring; Max. P.=maxillary palp; L.P.=labial palp]

This is a winged species with a long ovipositor, the longest of all known *Pempheres* parasites. This was for the first time taken in September 1937, when about 16 individuals were recovered either as larvae or as cocoons. In October as many as 26 have been obtained. It has been successfully bred in the laboratory and the life history more or less elucidated. It is a larval primary ectophagous parasite. It prefers healthy non-parasitised, full-grown host grubs and lays one egg (rarely two) on any part of the host body after it is rendered inactive by complete paralyzation. The egg (Plate XXV, fig. 2) is translucent elongate, cigar shaped and curved with extremities rounded. The cephalic end is much broader than caudal end. A maximum of two eggs has been noted per day per female. The egg-laying capacity in captivity has seldom risen over ten per female in cages. Parthenogenetic reproduction is fairly common, the resulting progeny being invariably males. The preoviposition period ranged from 3 to 12 days ordinarily and in some cases seemed to be considerably prolonged particularly in parthenogenetic cases where a maximum of 33 days has been recorded. Incubation period varied from 1 to 2 days averaging 1·4 days for 11 cases. Larval period varied from 4 to 6 days averaging 4·4 days for 11 cases. The full-grown larva (Plate XXV, figs. 3, 4) which is robust having clearly marked prominent urate cells, spins usually a cocoon before pupation. The prepupal and pupal periods ranged from 13 days to 16 days averaging 14 days for 8 individuals. The prepupal period alone ranged from 2 to 3 days averaging 2·3 days for 4 cases. The total life-cycle period varied from 17 to 22 days according to the season and fluctuations in temperature. The life period was seen prolonged in cooler months, namely November to February. The males have a slightly shorter life-cycle period than females, averaging 21 days for females and 19 days for males. The adult longevity reached a maximum of 73 days with honey solution or raisin but averaged 61 days for 5 individuals. This seems to be one of the most promising species. It is a large winged species and has greater potentiality than the smaller wingless *Spathius*. Above all it has a much longer ovipositor which can pierce and penetrate deeper into the stem and grubs which have tunnelled even into the central regions of the stem become accessible to the species. It has been recovered so far only in association with *Triumfetta rhomboidea*. It remains to be seen if the same will adapt itself to the environment of cotton fields.

Rhaconotus cleanthes Nixon (Plate XXVI).—This is a reddish brown Branconid varying in length from 2·2 to 4·5 mm. Nixon [1939] has described the new species.

This slender winged Braconid with an average length of 4 mm. has been recovered from *Triumfetta rhomboidea* during October 1937. Only a few cases of parasitism by the species in this food plant have come to the notice. The species has also been occasionally noted and taken from the same insect host from *Sida acuta* in Dhone and Kuniamuthur. It lends itself to artificial breeding in captivity to a certain extent. This is also a primary larval ectophagous parasite. It prefers only mature host grubs. Oviposition is very infrequent and erratic. The egg (Plate XXVI, fig. 2) is narrow, translucent with caudal end narrower than head end. The full-grown larva (Plate XXVI, figs. 3, 4) is elongate and slender with a brownish white

colour. The life cycle occupies from 16 to 24 days. The minimum pre-oviposition period is about 2 days but varies considerably. The egg period ranges from 1 to 2 days ; larval period from 4 to 6 days. A maximum capacity of 15 eggs has been noted for a single female. The adult longevity runs up to 30 days with raisin.

Rhaconotus menippus Nixon (Plate XXVII).—This is a decidedly darker species than the previous one and is of an average length of 3 mm. Nixon describes the species as being characterised by the division of tergite (2 plus 3) into three areas and by having the middle one of these areas differently sculptured from the other two. The fine striation surrounding the ocelli is also likely to be specific.

This parasite has been recovered only once parasitising *Pempheres* in association with this food plant. More often it has been noted to parasitise this weevil infesting another food plant, namely *Corchorus olitorius*. It has been also taken on several occasions as a parasite of another weevil, *Hypolixus truncatulus* in amaranthus. The general life history is similar to that of *R. cleanthes*.

Nematodes

Geomermis indica Steiner.—This Mermithid was for the first time discovered to be parasitic in mature *Pempheres* grubs infesting this plant host during September 1937. These have been, later occasionally taken from the same material from the same locality, namely Thondamuthur, during October and November. Apparently its range of occurrence is limited to this locality since it has not been encountered in materials from a few other places. In a few instances, these worms have been recovered also from later stages of the host insect such as prepupae and pupae.

The parasitized host grub does not show any marked external indication. The only differences that may sometimes be noted consist in the grub being inactive and swollen or discoloured. In one or two instances the emergence of the larval forms by forcing through the weakened body wall has been actually observed. Rarely also, the swollen abdomen of the host grub showed external curved ridges and grooves indicating the presence of the much curled worms inside.

These larval forms are dirty white, slender, thread-like worms less than $\frac{1}{2}$ mm. in length found in some numbers inside the body cavity of the host. In a single instance an actual count was made and eleven such forms were noted. These are, when mounted in a drop of distilled water on a slide, found to be motionless for a while but soon become active with wriggling and lashing movements. Through the kindness of Dr Steiner, Principal Nematologist, Washington, the worms have been identified as belonging to a new species—*Geomermis indica*. The genus *Geomermis* itself is said to be new and has not been described. According to Dr Steiner these forms are Mermithids without cross fibres in the cuticle, with eight longitudinal chords and six cephalic pupillae with a short semi-spherical vagina and with very short paired spicula. The few forms known in the genus are confined to the U. S. A. This forms the only record of the genus from outside that country. This is the first record of nematode parasitism in *Pempheres* and probably also in stem boring Curculionidae.

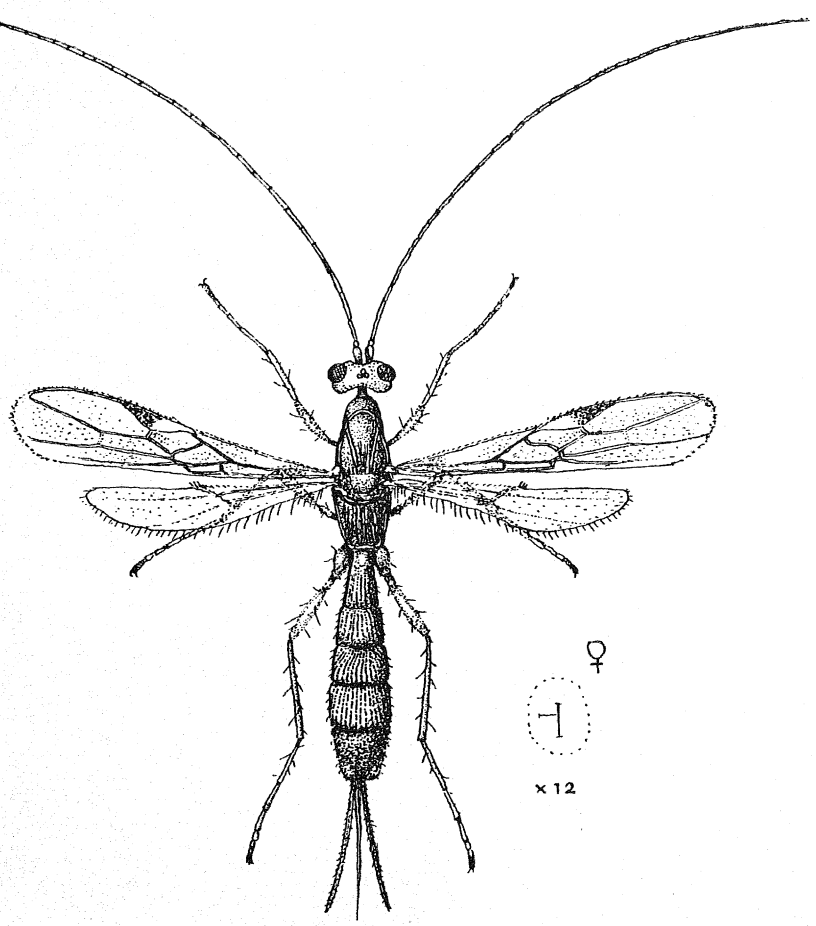


FIG. 1. Adult female



FIG. 2. Egg

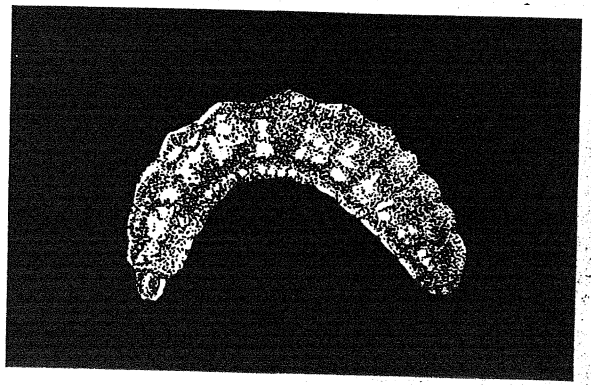


FIG. 3. Full-grown larva

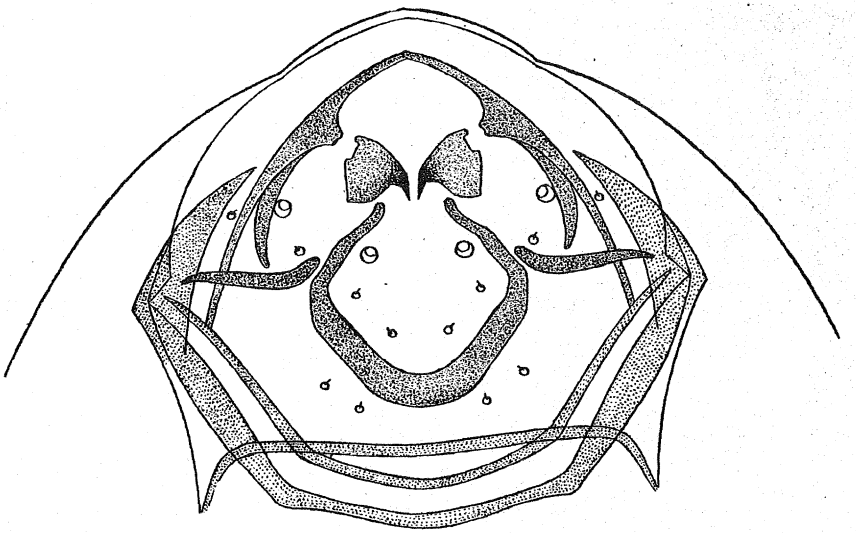
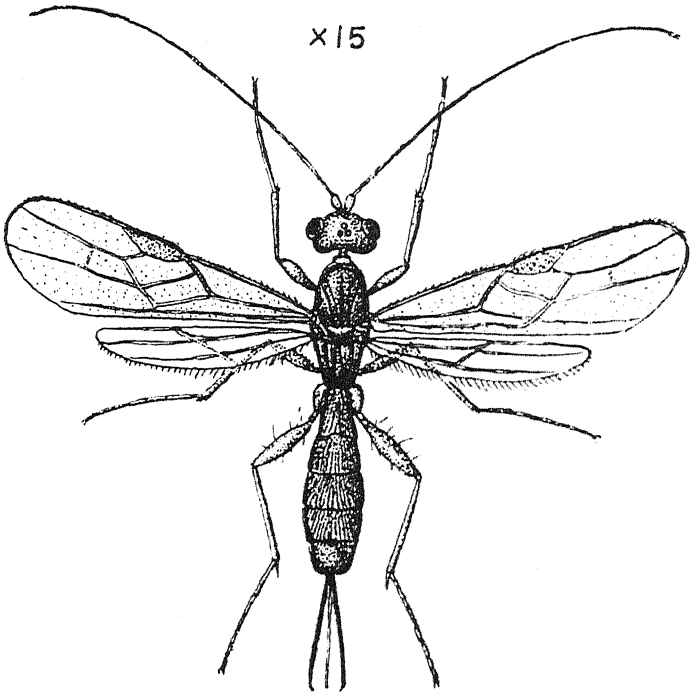


FIG. 4. Head and mouth-parts of full-grown larva

RHACONOTUS MENIPPUS NIXON



Adult female

The method of infection is not definitely known. Since these have been encountered only in the rainy season in October and November it may be that rain stimulates the female parent to ascend up these plants and penetrate the cracks, crevices and grub tunnels in the stem where eggs are laid. The host grub gets infested while feeding on plant tissue. It may also be that the larva that hatches pierces the body wall of the grub and occupies the body cavity. With the present state of our knowledge the economic significance of this phenomenon cannot be truly assessed. As factors of control, these may be at present regarded as of little importance.

Significance of infestation and parasitism in the food plant

Great stress has been recently laid by eminent authorities on the study of alternate food plants with a view to discover the primitive wild association of indigenous insect pests in any biological control project. Weeds and wild host plants were not seriously reckoned hitherto as hosts of this weevil. The few weeds which were noted to harbour the weevil in and around cotton fields were dismissed as of no importance except as probable minor nuclei for reinfestation of cotton crops. As for parasites, these were practically unknown from this source. The present studies have served to dispel such notions and have given a new orientation to the biological control of this insect.

Pempheres affinis is a polyphagous species and attacks a number of wild plants in a wide range of conditions. Incidentally this polyphagy constitutes a serious handicap in breeding resistant varieties. Further, the weevil appears to be a normal inhabitant of many regions beyond the limits of cotton cultivation. Profuse breeding of the weevil in a wild host plant like *T. rhomboidea* in virgin forest areas and the variety and comparative abundance of parasites in such haunts are of considerable significance. The majority of such parasites being absent in cotton fields is also a feature of importance. The ability of some of these to parasitise the weevil in different host plants is another eminently desirable feature. A thorough knowledge, therefore, of these parasites in relation to the weevil and its host plant appears to be essential for judging the possibility of utilisation of these species. Hence the necessity for an extended and elaborate examination of these alternate food plants is clearly brought out by these studies.

In a previous paper [1937] it has been suggested by the writer that the weevil might be indigenous to India by reason of its occurrence in *bhindi* in diverse situations far away and completely cut off from cotton cultivation, such as Dehra Dun in the United Provinces, Manantoddy hills in Malabar, etc. The present studies have served to emphasise this aspect and provide additional proof in support of this inference. This additional evidence seems to leave no room for doubt as to its place of origin since it would be otherwise impossible to explain the presence of such separate infestations in varied regions including sylvan associations and forest areas such as Siruvani, Wallayar forests, Kallar and Dhone hills in Malabar. The case of weeds and plants found in and near cultivated regions is quite different and is easy of interpretation as the infestations could have proceeded from cotton. The evidence in favour of the weevil's primitive association with *bhindi* still holds good but this plant

is at present a cultivated one though originally wild. Recent studies, therefore, raise the question whether such wild plants like *T. rhomboidea*, *Sida acuta*, *S. rhomboidea*, *Urena lobata*, etc. may not have had an earlier association with the weevil. Among such plants *T. rhomboidea* stands unique both in respect of heaviness of infestation and high rate of parasitism. In any attempt, therefore, in classifying the more important of the known food plants according to their length and primitiveness of association with the weevil, cotton will have to be ranked as recent, *bhindi* as having an older association and *T. rhomboidea* as having a still more primitive relationship with the pest. For quite another reason also cotton does not appear to constitute its natural food plant because its normal development in this host is arrested and great mortality is caused by such inherent factors as gumming. From a few trials in the field and in the laboratory the oviposition of adults bred from *Triumfetta* has been found to be poor in cotton. On the other hand oviposition of cotton-bred adults on *Triumfetta* stalks has been slightly better. Transfer of different stages of grubs from one plant to the other does not affect their development. These experiments in their behaviour suggest that *Triumfetta* may perhaps be its original food plant. Anyway, there seems to be little doubt that *Triumfetta rhomboidea* is the most preferred among its known food plants. The practical importance of these observations is the opening of a new avenue of investigation, namely the possibility of manipulation and liberation of suitable parasites from this source for colonization in cotton fields. A small though unconscious step in this direction has been started by the breeding section by the importation of this material for artificial weevil infestation of cotton crop in the breeding station. But systematic and planned attempts to encourage successful emergence and liberation of such parasites in conjunction with laboratory breeding, if and when necessary, seem to be full of promise.

ACKNOWLEDGEMENTS

The writer wishes to record his grateful thanks to the Indian Central Cotton Committee for providing the financial assistance and the Cotton Specialist for affording facilities for the studies. He is also thankful to fieldman Mr S. Royappan, who helped in the field collection of plants during the beginning of this study and Mr Tobias, who continued it. Thanks are also due to Fieldman Mr N. Muthuswami for assistance in preparing the tables. The writer is greatly indebted to Sir A. K. Guy Marshall and the specialsts of the Imperial Institute of Entomology for identification of weevils and parasites.

REFERENCES

Ahmad, T. (1939). *Ind. J. Agric. Sci.* **9**, 610-27
Ballard, E. (1923). *Mem. Dept. Agric. Ind. (Ent. Ser.)* **7**, No. 12
Dharmarajulu, K. *et al.* (1934). *Madras Agric. J.* **12**, 6
Ferriere, Ch. (1939). *Bull. Ent. Res.* **30**, 163
Fletcher, T. B. (1919). *Proc. Third Ent. Meeting Pusa* **1**, 202
Krishna Ayyar, P. N. (1936). *Madras Agric. J.* **24**, 417
——————— (1937). *Proc. of I Cotton Res. Workers' Conf., Bombay, 27*
Myers, J. G. (1935). *Bull. Ent. Res.* **26**, 181
Nixon, G. E. J. (1939). *Bull. Ent. Res.* **30**, 119
Ramakrishna Ayyar, T. V. (1918). *Madras Agric. Dept. Year Book*, 1
Smith, H. S. (1935). *J. Econ. Ent.* **28**, 873
Thompson, W. R. (1930). *E. M. B.* **29**

STUDIES ON THE ROOT-ROT DISEASE OF COTTON IN THE PUNJAB

VIII. FURTHER STUDIES ON THE PHYSIOLOGY OF THE CAUSAL FUNGI

BY

JAI CHAND LUTHRA, M.Sc., D.I.C. (Lond.), I.A.S.

Professor of Botany

AND

R. SAHAI VASUDEVA, B.Sc., Ph.D. (Lond.), D.I.C. (Lond.)

Assistant Cotton Mycologist

ASSISTED BY

MOHAMMAD ASHRAF, B.Sc. (Agri.)

Agricultural Assistant, Department of Botany, Agricultural Research Institute, Lyallpur

(Received for publication on 23 October 1939)

Introductory

IN view of the great losses to the cotton growers due to root-rot disease, the importance of the disease in the Punjab cannot be over-emphasized. The study of the physiological behaviour of the causal fungi *Rhizoctonia bataticola* = C. strain of Haigh = *Macrophomina phaseoli* and *Rhizoctonia solani* is of great importance in the discovery of the control measures for the disease.

The intensity and severity of attack of these fungi largely depends on the environmental conditions which, if favourable, tend to increase their activity. The kind of food, moisture content of the soil and temperature may accelerate their virulence.

The fungi under consideration are able to attack a considerable range of host plants and are not highly selective in their metabolism so much so that all the carbohydrates and nitrogen sources tested [Vasudeva, 1937] yield satisfactory growth.

These fungi do not show any appreciable growth under highly anaerobic conditions. Their growth is markedly retarded at 25 per cent concentration of carbon dioxide. Though the growth is arrested at higher concentrations of carbon dioxide yet the fungi are found to be viable even after prolonged exposure to highly anaerobic conditions when normal conditions are restored [Vasudeva, 1936]. Experiments have been conducted to determine whether different carbon compounds would support satisfactory growth under anaerobic conditions.

Material and methods

The two fungi used in this investigation were :—

Rhozoctonia bataticola (Maubl.) Ashby. = C. strain of Haigh = *Macrophomina phaseoli*	Isolated from diseased cotton roots.
Rhizoctonia solani (Kuhn. group)	Isolated from diseased cotton roots.

At the beginning of the work the purity of the cultures was ensured by taking a single hyphal tip in each case, after the method described by Brown [1924]. Stock cultures of the fungi were maintained in tubes of potato extract agar. The inocula for cultural work were invariably taken from cultures 10 to 20 days old.

The fungi were grown in liquid and on agar media containing the same ingredients and a single carbohydrate.

The following media, with or without agar, were employed :

1. Potato extract :—

Peeled potatoes	20 gm.
Agar	20 gm.
Distilled water	1,000 c. c.

2. Cotton root synthetic [Vasudeva, 1937] was used as basic medium. The nitrogenous constituent, peptone, normally used in this medium was replaced by ammonium sulphate calculated to yield an equivalent amount of nitrogen. And carbohydrate constituent was reduced to half the normal strength.

The composition of the medium as used in the experiments described in the present paper was as follows :—

Carbohydrate	10 gm.
Ammonium sulphate	2·16 gm.
K_3PO_4	1·9 gm.
$MgSO_4$	0·4 gm.
NaCl	0·6 gm.
$FeCl_3$	A trace.
Bromcresol purple (1 per cent)	1 c. c.
Bacto agar	20 gm.
Distilled water to make up	1,000 c. c.

The carbohydrates used were as follows :—

Maltose, glucose, sucrose, lactose, galactose, dextrin and soluble starch.

The media were divided into 40 c. c. lots unless otherwise mentioned in test tubes or Erlenmeyer's flasks of uniform size and capacity. Flasks of 125 c. c. capacity and test tubes 25 × 200 mm. and of 90 c. c. capacity were used throughout the course of these experiments.

The *p*H of media in all cases was brought to the neutral point, using bromcresol purple as indicator. Inoculations were made from cultures with active growth and as far as possible uniform size of inocula were introduced. Observations were made as to the time required for the acidification of the media and the amount of growth. Colour change of the medium from red to straw yellow colour, indicated the acidification of the medium, i.e. from *p*H 7 to approximately 5.

The experiments were conducted both at laboratory temperature and at 30°C.

Cultures grown on the agar medium were mostly surface growths, and were therefore exposed to the varied experimental conditions. Those grown in the liquid media were almost always submerged, except when the inocula were kept suspended on the surface of the medium by means of platinoid wire basket like structures.

Experimental results

(*a*) *Growth of* R. solani *and* R. bataticola *in liquid and agar media with different carbohydrates.*—The fungi were grown both in flasks and test tubes containing liquid and agar media. The test tubes with liquid media were placed upright in desiccators and arranged in such a manner that observations could be made without touching them as slight shaking or movement of the tubes would upset the growth in the liquid media. Results of typical experiments for *R. solani* and *R. bataticola* are summed up in Table I.

The results show that both in the liquid and agar media all the carbohydrates tested supported a fairly satisfactory growth and that the acidification of agar cultures occurred earlier than the liquid media. These results hold good both for tube and flask cultures. The inocula in the case of liquid media were submerged whereas in the agar media these were on the surface.

In the case of agar cultures in test tubes a beautiful yellow ring was formed along the upper surface of the medium. The breadth of the ring depending upon the depth to which the fungal hyphae had penetrated. A scanty and sparse growth was noticed in the control media lacking in carbohydrate constituent.

It was observed during the course of these experiments with *R. bataticola* that the colour change or the acidification was delayed in liquid media but did not occur at all in agar media when lactose or galactose were used as source of carbon.

The experiments were repeated a number of times at the room temperature as well as at 30°C. and results similar to the above were obtained.

(*b*) *Submerged and floating cultures.*—During some cultural experiments with liquid media in the laboratory it was observed that there were differences in the amount of growth and time required for acidification or colour change in the same set of flasks. Such variations appeared to be due to the position of the inocula. Experiments were, therefore, carried out to determine the effect of submerged and floating inocula on the growth and the time required for acidification of the cultures.

Fifty c. c. of the basal liquid medium, i.e. modified cotton root synthetic was put in Erlenmeyer flasks of 125 c. c. capacity. In the flasks containing the media platinoid wire loops were inserted through the plugs and suspended in such a manner that the loops just touched the central point on the surface of the medium. The flasks with media and loops were sterilized as usual and divided into two equal lots and inoculated with vigorously growing cultures of *R. bataticola* and *R. solani*. In one set the inocula were placed carefully on the loops in the flasks so that the inocula were kept floating on the surface of the medium whereas in the other set of flasks the inocula were

TABLE I

Days required for acidification and comparative growth on liquid and agar media with different carbohydrates for* R. solani *and* R. bataticola

Source of carbon	*R. solani*								*R. bataticola*							
	Liquid medium				Agar medium				Liquid medium				Agar medium			
	Test tubes		Flasks		Test tubes		Flasks		Test tubes		Flasks		Test tubes		Flasks	
	Growth (9 days)	Days for acidification	Growth (5 days)	Days for acidification	Growth (7 days)	Days for acidification	Growth (4 days)	Days for acidification	Growth (9 days)	Days for acidification	Growth (5 days)	Days for acidification	Growth (7 days)	Days for acidification	Growth (4 days)	Days for acidification
Maltose	++	9	++++	6	++++	4	++++	4	++++	7	++++	5	++++	3	++++	3
Glucose	++	7	+++	6	++++	4	++++	4	++++	7	+++	5	++++	3	+++	4
Sucrose	++	7	+++	6	++++	5	++++	4	++	10	+++	5	++++	3	+++	4
Lactose	++	7	++	8	++++	6	++	5	++	10	+	No change in 8 days	++	No change	+	No change
Galactose	++	9	++	8	++++	6	++++	4	++	10	+++	8	++++	Do.	++	Do.
Dextrin	++	9	++	6	++++	4	++	5	+++	8	++++	5	++++	3	++++	3
Soluble starch	++	9	++	6	++++	4	+++	4	++++	7	++++	5	++++	3	++++	3
No carbohydrate	Slight growth	No change	+	No change	+	No change	+	No change	+	No change	+	No change	+	No change	+	No change

* At laboratory temperature.
\+ Signs denote the amount of growth ; the larger the number the greater the amount of growth.

TABLE II

Acidification of cultures in relation to floating and submerged inocula

Source of carbon	*R. solani*						*R. bataticola*					
	Agar		Floating		Submerged		Agar		Floating		Submerged	
	Growth	Days for acidification	Growth	Days for acidification	Growth	Days for acidification	Growth	Days for acidification	Growth	Days for acidification	Growth	Days for acidification
Maltose	++++	4	++++	4	+++	5	++++	4	++++	5	++++	8
Glucose	++++	4	++++	4	++++	5	++++	4	++++	5	++++	7
Sucrose	++++	4	++++	4	++	6	++++	4	+	8	+	..
Lactose	+++	4	+++	5	+++	5	++	No change	+	28	+	37
Galactose	++++	4	++++	4	++	6	+++	Do.	+++	7	++	15
Dextrin	++++	4	++++	4	++	6	++++	4	++	7	+	24
Soluble starch	++++	4	++++	4	++	6	++++	4	+	10	+	22
No carbohydrate	+	No change	+	No change	+	No change	+	No change	+	No change	+	No change

inserted in the normal way and these got submerged in the medium. The inoculated flasks were arranged in an incubator at 30°C. in such a way that the observations could be made at a glance. The flasks were not moved or shifted throughout the course of these experiments in order to allow uniform and uninterrupted growth. Agar cultures in flasks were also set up for comparison.

The experiments were repeated several times and the results of a typical experiment are set out in Table II.

The data show that in the case of both the fungi the time required for acidification of submerged cultures is greater than the floating cultures. The growth in submerged cultures was comparatively slow. The cultures with the floating inocula almost correspond with agar cultures which are mainly surface growths. It is likely that the growth of the fungi in submerged cultures produces a by-product which if allowed to accumulate retards further growth. Such a by-product very likely seems to be of a volatile nature which is easily lost from surface cultures but is retained in the liquid medium in the case of submerged cultures.

It is clear from the results that the growth of these fungi is affected by the solid or liquid condition of the medium in which these are cultured and also on the position of the inoculum, i.e. submerged or floating.

The growth of these fungi is indicated as : + + + + = very good = 4, + + + = good = 3, + + = fair = 2, + = slight growth = 1 and multiplied with 100 to avoid fractions. The utilization quotient indicating the comparative availability of the food material was calculated by dividing growth × 100 by the number of days required for acidification [Moore, 1937]. The utilization quotients for agar, floating, and submerged cultures of *R. solani* and *R. bataticola* as estimated from Table II are given in Table III.

TABLE III

Utilization quotients for R. solani *and* R. bataticola *under normal atmospheric conditions*

Carbohydrate	*R. solani*			*R. bataticola*		
	Agar	Floating	Submerged	Agar	Floating	Submerged
Maltose	100	100	60	100	80	25
Glucose	100	100	80	100	80	57
Sucrose	100	100	30	100	13	..
Lactose	75	80	60	0	4	3
Galactose	100	100	30	0	43	13
Dextrin	100	100	30	100	29	4
Soluble starch	100	100	30	100	10	5
No carbohydrate	0	0	0	0	0	0

The utilization quotients are lower for submerged than for the floating cultures. In agar cultures the utilization quotients for *R. solani* almost correspond with the floating cultures but in the case of *R. bataticola* the utilization quotients are higher in agar than in floating cultures except in the lactose and galactose constituents where the quotient is lower and has fallen to zero.

(*c*) *Growth in various concentrations of carbon dioxide.*—The two fungi *R. solani* and *R. bataticola* were grown in test tubes on modified cotton root synthetic agar with different carbohydrates. The inoculated tubes were placed in desiccators which were then sealed. The test tubes were kept upright by sliding them singly through circular slits made in a piece of cardboard. This rendered making of observations comparatively easy. Carbon dioxide was let into these chambers by creating the required amount of vacuum with Cenco Megavac pump and by adjustment of pressure with the help of a manometer.

The experiments were conducted in atmosphere of 10, 20, 30 and 40 per cent carbon dioxide. Controls were kept under ordinary atmospheric conditions.

The results obtained by growing the fungi in different concentrations of carbon dioxide and in normal atmosphere are recorded in Table IV.

At 30 per cent concentration the growth of *R. solani* practically ceased whereas there was fair amount of growth in the case of *R. bataticola*. At 40 per cent concentration *R. solani* failed to grow but *R. bataticola* showed slight growth. An appreciable reduction in the amount of growth was noticed in the case of both the fungi even at twenty per cent concentration of carbon dioxide. The rate of growth in various concentrations of carbon dioxide was comparatively slow and the cultures took longer time for acidification than in normal atmosphere. The utilization quotients are inversely proportional to the increase in concentration of carbon dioxide.

(*d*) *Effect of nitrogen and oxygen.*—In another experiment the effect of nitrogen and oxygen on the growth and reaction of medium was studied. In two lots of evacuated chambers containing cultures of *R. solani* and *R. bataticola*, pure nitrogen or oxygen was let in. In another set of evacuated desiccators oxygen and nitrogen was let in the ratio of 50 : 50. Observations were made as to the growth of the fungi and the time required for acidification of the culture media was also noted. The data of such an experiment are given in Table V.

The results show that the growth and time required for acidification in the case of *R. solani* is not appreciably affected in an atmosphere of pure oxygen, but in the case of *R. bataticola* pure oxygen appears to have a depressing effect on the growth and the acidification of the medium is delayed. Pure nitrogen and nitrogen and oxygen (50 : 50) have no appreciable effect on the growth or time required for acidification of the medium in the case of either of the two fungi.

Thanks are due to the Indian Central Cotton Committee for kindly providing the necessary funds for carrying out these investigations.

TABLE IV

Days required for acidification of cultures in various concentrations of carbon dioxide

Carbohydrate	*R. solani*								*R. batatícola*							
	Atmospheric control		10 per cent carbon dioxide		20 per cent carbon dioxide		30 per cent carbon dioxide		Atmospheric control		10 per cent carbon dioxide		20 per cent carbon dioxide		30 per cent carbon dioxide	
	Growth (7 days)	Days for acidification	Growth (9 days)	Days for acidification	Growth (12 days)	Days for acidification	Growth (12 days)	Days for acidification	Growth (3 days)	Days for acidification	Growth (3 days)	Days for acidification	Growth (3 days)	Days for acidification	Growth (3 days)	Days for acidification
Maltose	++++	8	++++	10	Slight growth	No change	No growth	No change	++++	3	++++	4	+++	4	++	6
Glucose	++++	7	++++	9	Do.	Do.	Do.	Do.	++++	3	++++	4	+++	4	++	6
Sucrose	+++	8	++++	10	Do.	Do.	Do.	Do.	+++	4	+++	5	++	5	+	7
Lactose	++	No change in 12 days	+++	No change in 12 days	Do.	Do.	Do.	Do.	++	No change in 7 days	++	No change in 10 days	++	No change	+	No change
Galactose	+++	Do.	+++	Do.	Do.	Do.	Do.	Do.	++	Do.	++	Do.	++	Do.	+	Do.
Dextrin	+++	9	+++	11	Do.	Do.	Do.	Do.	++	5	+++	5	++	6	+	8
Soluble starch	+++	9	+++	11	Do.	Do.	Do.	Do.	++	5	++	5	++	6	+	8
No carbohydrate	+	No change	...	No change	Do.	Do.	Do.	Do.	+	No change	+	No change	+	No change	+	No change

TABLE V

Effect of nitrogen and oxygen on the growth and time of acidification

Carbohydrate	*R. solani*								*R. bataticola*							
	Atmospheric control		100 per cent nitrogen		100 per cent oxygen		50 per cent nitrogen and 50 per cent oxygen		Atmospheric control		100 per cent nitrogen		100 per cent oxygen		50 per cent nitrogen and 50 per cent oxygen	
	Growth (3 days)	Days for acidification	Growth (3 days)	Days for acidification	Growth (3 days)	Days for acidification	Growth (3 days)	Days for acidification	Growth (5 days)	Days for acidification	Growth (5 days)	Days for acidification	Growth (5 days)	Days for acidification	Growth (5 days)	Days for acidification
Maltose	++++	3	++++	3	++++	3	++++	3	++++	5	++++	5	++	7	++++	5
Glucose	++++	3	++++	3	++++	3	++++	3	++++	5	++++	5	++	7	+++	5
Sucrose	++++	3	++++	3	++++	3	++++	3	+++	6	++++	5	++	7	+++	6
Lactose	+++	6	+++	6	++	6	+++	6	+	No change	++	No change	+	No change	+	No change
Galactose	+++	6	+++	6	++	6	+++	6	+++	Do.	+++	Do.	++	Do.	++	Do.
Dextrin	++++	3	++++	6	++++	3	++++	6	+++	6	+++	6	++	7	++++	5
Soluble starch	++++	3	++++	3	+++	6	++++	3	+++	5	+++	5	++	7	++	7
No carbohydrate	+	No change	+	No change	+	No change	+	No change	+	No change	+	No change	+	No change	+	No change

SUMMARY

1. All the carbohydrates tested supported a fairly satisfactory growth of *R. solani* and *R. bataticola*. Agar media are comparatively more favourable for growth than the liquid media. Acidification also in the case of agar cultures is more rapid but in the case of *R. bataticola* the acidification is delayed in liquid media and does not occur at all even in agar media when lactose or galactose are used as source of carbon.

Floating cultures almost correspond with agar cultures in the rate of growth whereas in the case of submerged cultures the growth is slow and acidification of the cultures is delayed.

2. Carbon dioxide has a depressing effect on the growth and acidification of the media is delayed.

3. Effect of oxygen and nitrogen has also been tested.

REFERENCES

Brown, W. (1924). *Ann. Bot.* **38**, 401-4

Moore, E. J. (1937). *Phytopath.* **27**, 918-30

Vasudeva, R. Sahai (1936). *Ind. J. Agric. Sci.* **6**, 904-16

——————— (1937). *Ind. J. Agric. Sci.* **7**, 259-70 ; 575-87

STATISTICAL NOTES FOR AGRICULTURAL WORKERS

NO. 25. A SIMPLIFIED METHOD OF ANALYSIS OF QUASI-FACTORIAL EXPERIMENTS IN SQUARE LATTICE WITH A PRELIMINARY NOTE ON JOINT ANALYSIS OF YIELD OF PADDY AND STRAW

BY

K. R. NAIR

AND

P. C. MAHALANOBIS

Statistical Laboratory, Calcutta

(Received for publication on 28 September 1939)

(With one text-figure)

INTRODUCTION

FISHER'S Randomized Block and Latin Square designs have proved very useful in agricultural field experiments, but can be adopted only when a limited number of plots, usually not greater than ten or eleven, is included in a block or row and column. This limitation on the number of treatments which can be tested simultaneously is a serious handicap in the case of factorial experiments in which the number of treatment combinations keeps on increasing with the number of factors and with the number of the levels at which each factor is tested. The devices of confounding main effects in split-plot designs and interactions among sub-blocks are used to overcome this difficulty.

Recently Yates [1936, 1] has developed another method for keeping the block size within efficient limits when the number of treatments of a non-factorial experiment becomes large. The need of such single factor experiment occurs very frequently in practice when we have to make preliminary selection from a large number of new strains of a crop. Since only a single factor (e.g. variety, in this case) is involved, the several comparisons among the treatments cannot be classified under sets of main effects and interactions. For this reason the principle of straightforward confounding is apparently inapplicable here. Yates however used the ingenious idea of using a factorizable number (say, $v = p.\ q.\ r.\ldots\ldots$) for the number of varieties, and then viewing the varieties as all combinations of several factors (non-existent though) at levels $p, q, r, \ldots\ldots$, etc., for each group. We can then divide the varieties in v/p groups of p in each group, v/q groups of q in each group, v/r groups of r in each group, and so on. The comparisons among the v/p groups in the first type of division will correspond to the main effects and interactions of all factors excluding the first pseudo-factor ; the comparisons among the v/q groups in the second type of division will correspond to the main effects and interactions of

all factors excluding the second pseudo-factor ; the comparisons among the v/r groups in the third type of division will correspond to the main effects and interactions of all factors excluding the third pseudo-factor and so on. We can then confound these main effects and interactions of the various pseudo-factors, by assigning to a block only those varieties which occur together in the same group.

If there is sufficient land each group may be replicated a number of times, which should be the same (n, say) for each group. Thus the number of blocks in the experiment will be $vn\left(\frac{1}{p}+\frac{1}{q}+\frac{1}{r}+\ldots\right)$. The block size will not be the same if $p, q, r, \ldots$ are not equal. Thus there will be vn/p blocks of size p, vn/q blocks of size q, vn/r blocks of size r and so on. But instead of doing the experiment in blocks with v plots in each, we are thus able to reduce the block size to the comparatively smaller sizes of $p, q, r, \ldots$ plots. The designs which Yates got by this artifice of confounding of main effects and interactions of certain fictitious factors, super-imposed on the varieties, were given by him the name quasi-factorial designs .

The simpler and more efficient cases of this design occur when $p = q = r = \ldots$ Then v becomes some power of the number p. If, in addition, p is a prime number or power of a prime number, it is possible to confound all main effects and all interactions of the pseudo-factors. This will ensure the losing of equal amount of information from all varietal comparisons and thus give symmetry to the design with respect to every variety. This special design was called the 'symmetrical' quasi-factorial design.

When v is not a factorizable number the idea of introducing pseudo-factors fails completely and to meet this case Yates [1936, 2] has developed the brilliant idea of balanced incomplete randomized blocks. In these designs it is possible to secure equal accuracy for comparisons between every pair of varieties, and the symmetrical quasi-factorial design of $v = (p)^m$ occurs as a special case.

In the Calcutta Statistical Laboratory, Bose and Nair [1939] have developed a general class of designs called partially balanced incomplete block designs of which Yates' quasi-factorial designs for $(p)\,m$ varieties in blocks of $(p)\,m-1$ plots, and his balanced incomplete designs, happen to be special cases. While developing the method of analysis for this general class of designs, it was found that the method given by Yates for analysing the data from quasi-factorial experiments with p^2 varieties in blocks of p plots may be replaced by a simpler method. One of the objects of this note is to illustrate this new procedure of analysis with the help of data from a quasi-factorial experiment on rice.

In the season of 1937-38 two quasi-factorial experiments with 49 and 100 varieties of paddy were laid out by Mr S. C. Chakravarty at the Chinsurah Farm, Bengal, in 28 randomized blocks of 7 plots and 40 randomized blocks of 10 plots respectively. The designs were prepared at the Statistical Laboratory. In the experiment with 100 varieties it is impossible to achieve symmetry between every pair of varieties as 10 is not a power of a prime number. In the other experiment symmetry could have been achieved if the shape of the experimental piece of land was such as to accommodate four 7×7 Latin Squares. As this was not possible the symmetry was sacrificed, and in both experiments

main effects only of the pseudo-factors were confounded. We shall use the second experiment for our illustration.

Besides the usual analyses of variance for grain and straw separately, the analysis of covariance also has been worked out. In an exploratory experiment with large number of varieties like the present one, it is not wise to limit the criterion of selection of strains to one character, namely, yield of grain alone. It is desirable to take into consideration the yield of both grain and straw (and also of other characters of economic importance as necessary); and for this purpose it is essential to include in the analysis the covariance between characters. Unfortunately adequate tests of significance and necessary tables for this purpose are not yet available. The problem is, however, receiving increasing attention [Lawley, 1938, 1939; Roy, 1939, 1, 2], and we may expect that necessary tables of significant levels will be available for this purpose in the near future. In the meantime we are taking this opportunity of explaining the procedure for calculating the various sums of products which will be needed in covariance analysis.

As a preliminary step, we have used the covariance analysis for a brief discussion of the method of selecting the varieties when the yields of grain and straw are both taken into consideration.

Details of lay-out

One hundred *aman* strains (other than *patnais*), a list of which is given in the appendix were selected for this experiment. These strains were assigned, at random, one hundred serial numbers 00, 01, 02,.....09, 10, 11, ...19, ... 90, 91,.....99, which are noted in column (1) of the appendix. These numbers were then written in the form of a 10×10 square lattice of the following pattern :—

00	10	20	30	40	50	60	70	80	90
01	11	21	31	41	51	61	71	81	91
02	12	22	32	42	52	62	72	82	92
03	13	23	33	43	53	63	73	83	93
04	14	24	34	44	54	64	74	84	94
05	15	25	35	45	55	65	75	85	95
06	16	26	36	46	56	66	76	86	96
07	17	27	37	47	57	67	77	8	97
08	18	28	38	48	58	68	78	88	98
09	19	29	39	49	59	69	79	89	99

The variety occurring in the i-th column and j-th row of this square is denoted as variety [ij] in which both i and j vary from 0 to 9.

The varieties bearing numbers occurring in the same row or in the same column constitute a set. It is clear that there are only 20 such sets, of which 10 sets correspond to the 10 columns and the other 10 sets correspond

to the 10 rows of the above square. The first 10 sets will be said to constitute group I, and the second 10 sets to constitute group II.

Each set must be replicated in the same number of randomized blocks according to the availability of the land. In this experiment only two replications were used, so that we had 40 randomized blocks giving four replications of each variety. The size of each plot was 8 ft. 3 in. × 8 ft. 3 in. Leaving a border of 9 in. all around, the net size came to 7 ft. 6 in. ×7 ft. 6 in.

The two replicated blocks of each of the 20 sets were first assigned at random among the total of 40 blocks. The 10 varieties of a set were allotted in a serial order in a random direction in one of the blocks assigned to that set, and in the other block they were randomized. The actual field layout is shown on the next page. The blocks have been numbered 1 to 40 ; and Table II gives, besides other things, the serial numbers of the blocks in which each set of the two groups was replicated.

Season and nature of crop

The season was quite favourable for rice ; and transplanting for this experiment was done on 28th July 1937. The rainfall was slightly above normal, and the distribution was quite regular ; and from the agricultural point of view the crop was considered to be normal. The normal rainfall and the rainfall during 1937-38 as recorded at the Chinsurah Farm are shown in Table I.

Table I

Rainfall at Chinsurah Farm during the season 1937-38

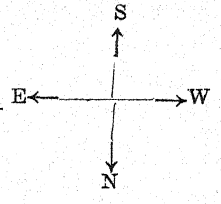
Month	Normal rainfall	Rainfall during the year 1937-38	Difference	Number of rainy days
April 1937	2·46	1·76	—0·70	2
May 1937	5·85	3·24	—2·61	10
June 1937	10·56	14·55	+3·99	14
July 1937	11·28	9·43	—1·85	25
August 1937	11·64	12·66	+1·02	21
September 1937	8·40	11·49	+3·09	21
October 1937	4·09	4·40	+0·31	6
November 1937	0·66	*Nil*	—0·66	*Nil*
December 1937	0·19	*Nil*	—0·19	*Nil*
January 1938	0·38	0·25	—0·13	1
February 1938	1·20	1·81	+0·61	3
March 1938	1·58	0·32	—1·26	1
Total	58·29	59·91	+1·62	104

Primary data

The primary data consist of yields of grain and straw expressed in ounces per plot. These are fully set out in Table II (*a*, *b*). The yield of straw was determined with less precision than the yield of grain. The total sum of

squares with 399 degrees of freedom, and the block sum of squares with 39 degrees of freedom were calculated directly from Table II (*a*, *b*) for yield of grain as well as yield of straw, and also the corresponding sum of products. It is not necessary to give details about the calculation of these quantities.

Lay-out plan of the experiment



	94	84	74	64	34	14	04	54	44	24	Block No. 40		
	65	20	98	05	91	70	20	53	78	30	63	76	40
	35	21	94	95	41	71	10	73	08	31	66	66	41
	85	22	90	75	21	72	30	93	68	32	60	56	42
	15	23	97	45	11	73	60	03	58	33	61	26	43
	55	24	92	15	31	74	80	83	18	34	68	16	44
	95	25	96	35	01	75	50	23	98	35	69	06	45
	45	26	99	55	71	76	00	13	28	36	64	96	46
	25	27	91	25	81	77	70	63	38	37	67	46	47
	75	28	93	85	51	78	40	43	88	38	62	86	48
	05	29	95	65	61	79	90	33	48	39	65	36	49
Block No.	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
	47	80	00	89	60	46	39	97	54	10	11	50	50
	42	81	07	99	10	26	34	67	84	11	18	57	51
	41	82	04	49	70	76	31	27	44	12	15	51	52
	43	83	01	79	20	66	37	77	64	13	17	55	53
	49	84	03	69	80	06	32	07	04	14	13	53	54
	48	85	08	09	30	16	35	17	14	15	14	54	55
	45	86	02	19	00	36	36	37	94	16	19	56	56
	44	87	06	29	50	56	30	87	74	17	12	58	57
	46	88	09	39	90	86	33	57	24	18	10	52	58
	40	89	05	59	40	96	38	47	34	19	16	59	59
Block No.	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
	71	57	60	03	00	79	02	29	90	86	01	38	82
	78	37	61	13	01	59	52	23	91	81	71	58	32
	73	87	62	83	02	39	92	22	92	80	41	88	02
	76	77	63	43	03	99	32	20	93	88	11	28	22
	79	67	64	53	04	49	72	28	94	83	31	78	92
	72	17	65	93	05	69	62	27	95	82	81	08	42
	70	97	66	33	06	89	82	21	96	89	21	98	52
	74	07	67	73	07	09	12	24	97	85	61	68	12
	77	47	68	63	08	29	22	26	98	87	91	18	62
	75	27	69	23	09	19	42	25	99	84	51	48	72
Block No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**

TABLE

Yield of grain and of straw in each plot (upper figures

Group

Set 1	Bl. 5	Bl. 16	Set 2	Bl. 23	Bl. 24	Set 3	Bl. 8	Bl. 28	Set 4	Bl. 20	Bl. 36	Set 5	Bl. 14	Bl. 39
00	46·5	64·0	10	52·5	43·0	20	42·0	51·5	30	40·0	63·0	40	50·0	52·0
	40	58		68	52		48	84		46	80		56	80
01	49·0	54·5	11	34·0	42·0	21	40·0	45·5	31	56·5	59·0	41	56·0	41·5
	66	68		58	82		52	80		56	86		72	80
02	41·0	49·5	12	51·0	42·5	22	42·5	59·0	32	41·0	48·5	42	49·5	46·0
	48	60		66	56		56	84		64	82		78	68
03	42·5	38·5	13	51·5	50·0	23	40·0	55·0	33	38·5	57·5	43	56·5	47·5
	42	58		82	58		38	72		46	72		64	78
04	40·5	48·0	14	51·5	58·5	24	45·0	61·0	34	53·5	55·5	44	48·0	54·5
	56	80		60	62		58	94		62	66		64	70
05	44·0	43·5	15	48·5	48·0	25	49·0	59·5	35	41·5	57·5	45	58·0	67·5
	46	46		80	80		68	102		48	74		64	78
06	42·5	47·5	16	42·0	40·5	26	47·5	54·5	36	44·5	52·5	46	53·0	61·0
	40	52		70	60		64	74		48	60		66	76
07	43·0	51·5	17	40·0	49·5	27	43·5	61·0	37	47·5	60·0	47	55·0	56·5
	50	64		60	76		48	74		74	84		70	72
08	51·0	54·0	18	44·0	60·5	28	40·0	52·5	38	36·5	57·0	48	58·5	59·0
	52	60		68	98		54	72		38	64		64	68
09	48·0	44·0	19	36·0	45·0	29	44·0	60·0	39	51·0	51·0	49	53·5	56·5
	64	52		52	72		56	78		60	66		76	68

II (*a*)

indicate grain yield ; lower figures indicate straw yield)

I

Set 6	Bl. 25	Bl. 26	Set 7	Bl. 3	Bl. 37	Set 8	Bl. 1	Bl. 32	Set 9	Bl. 10	Bl. 15	Set 10	Bl. 9	Bl. 29
50	50·5	56·5	60	38·0	44·5	70	44·0	62·0	80	48·0	54·0	90	44·5	74·5
	58	68		56	74		68	110		52	54		54	106
51	48·0	56·5	61	41·0	60·0	71	55·0	61·0	81	46·0	53·5	91	44·5	53·0
	56	64		50	76		56	84		52	68		54	72
52	44·5	55·5	62	35·5	55·0	72	54·0	60·0	82	35·5	43·5	92	41·0	51·5
	48	56		40	78		72	92		38	50		48	82
53	49·0	51·5	63	46·5	61·0	73	51·5	57·0	83	42·0	52·5	93	39·0	55·5
	66	74		44	72		60	102		46	64		46	74
54	46·5	53·0	64	41·5	58·5	74	51·5	55·5	84	52·5	49·5	94	44·5	63·0
	70	80		60	82		64	72		74	78		48	106
55	50·0	53·5	65	45·5	54·0	75	54·5	55·5	85	40·0	42·0	95	35·5	44·0
	64	64		74	86		68	74		56	64		46	64
56	46·0	43·5	66	38·0	28·0	76	46·0	52·0	86	39·0	47·5	96	47·5	68·0
	64	54		56	84		68	80		54	58		52	86
57	56·0	51·0	67	48·5	57·0	77	48·5	50·5	87	45·0	41·0	97	47·0	76·0
	66	62		48	70		72	72		52	56		62	122
58	50·0	50·5	68	40·0	47·5	78	46·0	50·0	88	50·5	49·0	98	52·0	57·5
	58	60		68	80		82	82		50	54		66	84
59	36·5	42·5	69	43·5	45·0	79	48·5	51·0	89	43·5	40·0	99	54·0	58·0
	52	58		74	80		48	54		60	56		60	80

TABLE

Yield of grain and of straw in each plot (upper figures

Group

Set 1	Bl. 18	Bl. 33	Set 2	Bl. 11	Bl. 31	Set 3	Bl. 7	Bl. 13	Set 4	Bl. 4	Bl. 34	Set 5	Bl. 22	Bl. 40
00	52·5	61·0	01	48·0	63·0	02	37·5	50·0	03	41·0	57·0	04	46·0	57·5
	48	52		56	78		44	64		48	64		68	78
10	51·5	54·0	11	38·5	42·0	12	45·5	55·5	13	43·0	52·5	14	53·5	75·0
	68	76		46	72		62	74		50	62		60	90
20	51·5	50·0	21	38·0	48·0	22	49·5	50·0	23	45·0	48·0	24	41·5	64·0
	64	80		52	80		64	64		48	50		50	84
30	46·5	53·5	31	47·0	59·0	32	36·0	41·0	33	42·0	55·5	34	45·5	69·0
	56	82		40	72		48	72		50	64		50	96
40	44·0	55·5	41	43·5	60·0	42	43·5	40·5	43	37·0	50·0	44	47·5	57·0
	52	64		60	82		64	60		40	60		76	72
50	45·0	53·0	51	50·5	48·5	52	40·0	51·0	53	43·0	52·0	54	54·0	60·0
	62	66		54	60		40	56		76	112		96	84
60	49·0	49·5	61	47·0	56·0	62	35·5	58·5	63	46·0	56·5	64	53·5	64·0
	78	82		60	64		42	80		46	62		88	76
70	48·0	50·0	71	47·0	58·5	72	41·0	61·5	73	44·0	57·5	74	40·5	57·0
	66	72		48	62		58	82		56	84		52	80
80	55·5	56·0	81	42·0	52·5	82	37·0	38·5	83	40·0	54·0	84	52·0	62·0
	56	68		50	64		34	42		48	64		78	82
90	42·0	58·0	91	49·0	49·0	92	35·5	44·0	93	37·5	60·0	94	42·5	70·0
	48	64		56	82		38	58		48	94		58	116

II (*b*)

indicate grain yield ; lower figures indicate straw yield)

II

Set 6	Bl. 27	Bl. 30	Set 7	Bl. 19	Bl. 38	Set 8	Bl. 2	Bl. 21	Set 9	Bl. 12	Bl. 35	Set 10	Bl. 6	Bl. 17
05	60·0	66·5	06	46·5	56·0	07	45·0	47·5	08	51·5	62·0	09	41·0	47·0
	62	82		52	66		58	64		52	74		42	62
15	59·0	53·5	16	45·5	55·5	17	38·0	44·0	18	56·5	62·5	19	45·0	44·0
	98	80		64	82		62	74		102	102		56	68
25	60·0	54·0	26	51·0	57·5	27	57·0	58·0	28	45·0	49·0	29	52·0	49·5
	82	80		72	82		64	66		56	60		68	68
35	70·5	62·5	36	47·0	50·5	37	37·0	39·0	38	41·5	52·0	39	51·0	39·5
	100	82		52	62		62	60		48	62		60	48
45	64·5	65·0	46	58·5	63·5	47	45·0	41·0	48	51·5	54·5	49	42·0	50·5
	68	76		66	78		52	46		60	56		52	66
55	60·0	49·5	56	42·0	46·5	57	38·5	39·5	58	43·5	60·0	59	35·5	34·5
	98	66		60	76		50	58		58	110		50	48
65	65·5	52·5	66	41·5	32·0	67	45·5	55·0	68	45·5	49·5	69	32·5	39·0
	82	80		76	86		48	62		78	82		54	78
75	61·0	65·0	76	51·5	31·0	77	36·5	47·5	78	37·0	56·0	79	38·5	49·5
	70	82		82	82		50	64		72	92		34	50
85	53·5	48·5	86	42·5	54·0	87	39·0	38·5	88	53·5	64·5	89	38·5	51·5
	80	66		52	68		44	44		56	68		50	72
95	49·5	48·5	96	43·0	63·0	97	45·0	58·5	98	47·5	53·5	99	43·5	52·5
	74	90		48	76		60	72		64	68		52	64

Sum of squares and products due to varieties

It is in the calculation of the sum of squares and of products for variety, with 99 degrees of freedom, that all the complications of analysis set in. But once these sums are obtained, the residual sum of squares may be obtained by subtraction : Total *minus* Blocks *minus* Varieties.

The table of analysis of variance given by Yates [1936] mentions eleven sources of variation, of which five go to make up the variation among blocks, three go to make up the variation among varieties and three go to uncontrolled variation (namely, residual). Speaking generally, we need not take the trouble of calculating the sums of squares due to each of these eleven sources of variation. We are mostly interested to find out the value of the sums of squares for the three items : Blocks, Varieties and Residual ; and this is what we shall consider in the present paper.

The sums of squares and sum of products due to blocks are easily obtained from the totals of the 40 blocks. In getting the sums of squares and sum of products due to varieties, we are using a new procedure which simplifies considerably the computational work.

New procedure

We have 40 blocks with 10 plots each. We first calculate the mean yield of grain of each block. We next subtract from every plot yield the mean yield of the block in which the plot is located ; and call these the corrected values of the yield. There are four plots for each variety ; we next add the four corrected values of yield of each variety, and write this quantity as Q_{ij} for variety [ij]. It is obvious that the sum of the 100 values of Q_{ij} is zero. It is also clear that Q_{ij} can be calculated more easily by taking 10 times the total yield of variety [ij] and subtracting from it the sum of the total yields of the four blocks in which it has occurred, and then dividing the result by 10.

We then arrange Q_{ij} in a two-way table as shown in Table III ; and obtain the marginal means $\overline{Q}_i$ and $\overline{Q}_j$. If V_{ij} be the estimate of the effect of the variety [ij] on yield of grain, as measured from the general mean, we have

$$V_{ij} = \tfrac{1}{4} (Q_{ij} + \overline{Q}_i + \overline{Q}_j) \qquad (1)$$

which is obtained from Bose and Nair's general formula, after suitable substitution and simplification*.

It is easy to calculate V_{ij} from Table III. The mean of all V_{ij} will be zero. As it is usual to present varietal means instead of varietal effects, we may add to each V_{ij} the general mean for the whole experiment, and get the varietal means shown in Table IV. It should be noted that the varietal mean shown here is not the 'crude' mean of the observed yields of the four plots under a given variety, but is the mean yield per plot of the given variety after adjusting for block effects. These adjusted varietal means are, therefore, comparable among themselves. In Table IV we thus obtain the summary of the results of the experiment before calculating the sum of squares. This is only logical, as estimation should precede tests of significance.

---

* For Yates' quasifactorial designs of p^2 varieties in blocks of p plots forming l groups of p sets each, and with r replications of each variety,

$$V_{ijk\ldots} = \frac{1}{r(l-1)} \left\{ (l-1) Q_{ijk\ldots} + \overline{Q}_{i\ldots} + \overline{Q}_{.j\ldots} + \overline{Q}_{..k\ldots} + \ldots \right\}$$

In our case, $l=2$, $=4$.

TABLE III

Values of Q_{ij} (yield of grain)

j \ i	0	1	2	3	4	5	6	7	8	9	Total	Mean ($\bar{Q}_j$)
0	27·10	5·35	—6·90	—0·80	—9·10	3·35	—14·35	—4·00	19·45	11·35	31·45	3·145
1	21·50	—35·25	—26·50	21·60	—5·70	5·75	12·55	17·40	3·85	—8·25	6·95	0·695
2	—5·45	12·30	12·55	—23·85	—17·65	2·80	2·60	21·95	—26·10	—22·20	—43·05	—4·305
3	—11·45	7·80	—7·45	—3·85	—13·15	0·30	21·10	8·45	0·90	—9·20	—6·55	—0·655
4	—13·50	34·25	1·00	11·10	—12·20	3·25	13·55	—12·10	13·35	3·75	42·45	4·245
5	2·80	—0·95	6·30	13·90	30·10	—2·95	7·85	13·70	—24·35	—44·45	1·95	0·195
6	0·35	—7·40	13·35	—4·55	30·15	—18·90	—51·10	—22·75	—6·30	18·60	—48·55	—4·855
7	3·20	—11·05	30·70	—7·20	0·00	—3·55	23·75	—11·90	—17·45	31·95	38·45	3·845
8	20·55	26·80	—16·45	—17·85	11·85	1·30	—14·90	—20·05	22·40	1·80	15·45	1·545
9	—2·00	—10·75	18·50	3·60	6·80	—38·25	—20·45	—5·60	—5·65	15·25	—38·55	—3·855
Total .	43·10	21·10	25·10	—7·90	21·10	—46·90	—19·40	—14·90	—19·90	—1·40	0	0
Mean ($\bar{Q}_i$)	4·31	2·11	2·51	—0·79	2·11	—4·69	—1·94	—1·49	—1·99	—0·14	0	

TABLE IV

Estimated varietal effects on yield of grain (V_{ij} + g. m.)*

j \ i	0	1	2	3	4	5	6	7	8	9
0	58·2125	52·2250	49·2625	49·9625	48·6125	50·0250	46·2875	48·9875	54·7250	53·1625
1	56·2000	41·4625	43·7500	54·9500	48·8500	50·0125	52·4000	53·7250	50·2125	47·6500
2	48·2125	52·1000	52·2625	42·3375	44·6125	48·0250	48·6625	53·6125	41·4750	42·9125
3	47·6250	51·8875	48·1750	48·2500	46·6500	48·3125	54·2000	51·1500	49·1375	47·0750
4	48·3375	59·7250	51·5125	53·2125	48·1125	50·2750	53·5375	47·2375	53·4750	51·5375
5	51·4000	49·9125	51·8250	52·9000	57·6750	47·7125	51·1000	52·6750	43·0375	38·4750
6	49·5250	47·0375	52·3250	47·0250	56·4250	42·4625	35·1000	42·3000	46·2875	52·9750
7	52·4125	48·3000	58·8375	48·5375	51·0625	48·4750	55·9875	47·1875	45·6750	58·4875
8	56·1750	57·1875	46·4750	45·3000	53·4500	49·1125	45·7500	44·5750	55·0625	50·3750
9	49·1875	46·4500	53·8625	49·3125	50·8375	37·8750	43·0125	46·8375	46·7000	52·3875

*General mean (g. m.)=49·58.

TABLE V

Values of Q'ij (yield of straw)

j \ i	0	1	2	3	4	5	6	7	8	9	Total	Mean ($\bar{Q}'_j$)
0	—42·6	—2·4	10·0	6·0	—19·6	—0·6	24·4	37·6	—14·0	0·4	—0·8	—0·08
1	34·0	—1·8	4·6	2·6	29·0	—14·0	—9·0	—21·8	—3·4	—1·0	19·2	1·92
2	—8·8	7·4	17·8	23·8	14·2	—38·8	—9·8	41·4	—64·2	—29·8	—46·8	—4·68
3	—20·8	—6·6	—50·2	—18·2	—21·8	81·2	—33·8	31·4	—14·2	—1·8	—54·8	—5·48
4	18·4	—17·4	—3·0	—7·0	—12·6	52·4	17·4	—33·4	45·0	33·4	93·2	9·32
5	—34·0	42·2	36·6	16·6	—15·0	8·0	27·0	—13·8	—7·4	—27·0	33·2	3·32
6	—38·4	1·8	18·2	—43·8	6·6	—8·4	28·6	25·8	—19·8	—17·4	—46·8	—4·68
7	9·8	20·0	0·4	36·4	—17·2	—4·2	—23·2	—6·0	—33·6	58·8	41·2	4·12
8	—14·2	92·0	—35·6	—57·6	—35·2	19·8	30·8	38·0	—27·6	— 1·2	9·2	0·92
9	—4·4	—2·2	20·2	—7·8	6·6	—30·4	36·6	—76·2	10·2	0·6	—46·8	—4·68
Total .	—101·0	133·0	19·0	—49·0	—65·0	65·0	89·0	23·0	—129·0	15·0	0	0
Mean ($\bar{Q}'_i$) .	—10·10	13·30	1·90	—4·90	—6·50	6·50	8·90	2·30	—12·90	1·50	0	

TABLE VI

Estimated varietal effects on yield of straw (V'_{ij} + g. m.)*

j \ i	0	1	2	3	4	5	6	7	8	9
0	52·50	68·40	68·65	65·95	59·15	67·15	74·00	75·65	58·95	66·15
1	72·15	69·05	67·80	65·60	71·80	64·30	66·15	61·30	62·10	66·30
2	59·80	69·70	69·45	69·25	66·45	56·45	64·30	75·45	45·25	57·45
3	56·60	66·00	52·25	58·55	57·25	86·25	58·10	72·75	57·55	64·25
4	70·10	67·00	67·75	65·05	63·25	82·75	74·60	60·25	76·05	76·75
5	55·50	80·40	76·15	69·45	61·15	70·15	75·50	63·65	61·45	60·15
6	52·40	68·30	69·55	52·35	64·55	64·05	73·90	71·55	56·35	60·55
7	66·65	75·05	67·30	74·60	60·80	67·30	63·15	65·80	55·10	81·80
8	59·85	92·25	57·50	50·30	55·50	72·50	75·85	76·00	55·80	66·00
9	60·90	67·30	70·05	61·35	64·55	58·55	75·90	46·05	63·85	65·05

*General mean (g. m.)=65·695

Similar calculations can be made for the yield of straw. Let Q'_{ij} and V'_{ij} correspond, in the case of straw, to Q_{ij} and V_{ij} defined in the case of yield of grain. Tables V and VI give the values of Q'_{ij} and V'_{ij} respectively.

Having calculated the values of these four quantities (Q_{ij}, V_{ij} and Q'_{ij}, V'_{ij}) we get the sum of squares due to varieties in the case of yield of grain with the help of the formula

$$\sum_{i=0}^{9} \sum_{j=0}^{9} V_{ij}\, Q_{ij} \qquad (2)$$

and the sum of squares due to varieties in the case of yield of straw from the formula

$$\sum_{i=0}^{9} \sum_{j=0}^{9} V'_{ij}\, Q'_{ij} \qquad (3)$$

The sum of products due to varieties for yield of grain and yield of straw can be obtained by either of the two expressions :

$$\sum_{i=0}^{9} \sum_{j=0}^{9} V_{ij}\, Q'_{ij} \text{ or } \sum_{i=0}^{9} \sum_{j=0}^{9} V'_{ij}\, Q_{ij} \qquad (4)$$

which are identical. It is convenient, therefore, to calculate the product independently in both ways which furnishes a check on the whole set of calculations.

Tests of significance

Table VII gives the full analysis of variance and covariance.

Table VII

Analysis of variance and covariance

Variation due to	D. F.	Sum of product of grain and straw	Sum of squares		Coefficient of correlation
			Grain	Straw	
Blocks .	39	21917·10	12801·80	44680·79	+0·9164
Varieties .	99	1737·68	7694·07	23243·79	+0·1299
Error .	261	7230·22	5765·70	21074·21	+0·6559
Total .	399	30885·00	26261·57	88998·79	

Ratios of variances due to varieties and residual show that there are significant differences among the varieties with respect to yield of grain as well as of straw. These are shown in Table VIII.

TABLE VIII

Test of significance of varietal effects

Variation due to	D. F.	Variance		Ratio of variances		Expected R. V.	
		Grain	Straw	Grain	Straw	5 per cent	1 per cent
Blocks . .	39	328·26	1145·66				
Varieties .	99	77·71	234·79	3·52	2·91	<1·57	<1·88
Error . .	261	22·09	80·74				
Total .	399						

The standard error per plot for yield of grain is 4·70 or 9·48 per cent of mean. The standard error per plot for yield of straw is 8·98 or 13·67 per cent of mean. These compare well with the precision of ordinary randomized block experiments.

Tables IV and VI supply the summary of results from which detailed tests of significance can be used for differences between any pair of varieties. The varietal means were calculated correct to four decimal places for grain and two decimal places for straw in order to maintain a high order of precision in the sums of squares and of products.

The standard error of the differences between two varieties occurring in the same row or column is $\sqrt{(\frac{2}{4} \times \frac{1}{10})}$ times the standard error per plot, which works out to be 3·49 for grain and 6·66 for straw. The corresponding critical differences, at 5 per cent and 1 per cent levels, are respectively 6·87 and 9·05 for grain and 13·12 and 17·29 for straw.

The standard error of the difference between two varieties not occurring in the same row or column is $\sqrt{(\frac{2}{4} \times \frac{1}{10})}$ times the standard error per plot and works out to be 3·64 for grain and 6·95 for straw. The corresponding critical differences, at 5 per cent and 1 per cent levels, are respectively 7·16 and 9·44 for grain and 13·69 and 18·04 for straw.

There are 100 C_2 or 4950 comparisons between all pairs of varieties. Of these, 900 belong to pairs occurring in the same row or column ; and 4050 to pairs not having a row or column in common with them. Thus, for example, of the three varieties numbered 42, 45 and 82, the pair formed with 42 and 45 and the pair formed with 42 and 82 belong to the first kind of comparisons ; and the pair formed with 45 and 82 belongs to the second kind of comparisons. It will be noted that comparisons of the second kind have a larger error than the comparisons of the first kind. This is due to the fact that varietal pairs of the second kind do not occur together in the same block. Comparisons among them are thus affected by a greater amount of block variation than comparisons among pairs of the first kind which occur together in the same block.

Two more tables may be constructed rearranging the values of Tables IV and VI according to their decreasing magnitude, to show at a glance which varieties form classes of higher or lower yielders of grain and of straw,

This has been done in another way in Table IX, which shows against each variety its rank for yield of grain as well as for yield of straw.

TABLE IX

Ranked position of the varieties (upper figures indicate the rank for yield of grain ; lower figures indicate the rank for yield of straw)

i	0	1	2	3	4	5	6	7	8	9
	4	31	51	47	58	45	83	55	13	22
0	94	35	34	51	78	42	18	12	79	47
	8	97	89	12	56	46	27	16	44	70
1	22	33	37	53	23	58	48	69	66	46
	65	32	30	94	87	68	57	17	96	92
2	77	28	31	32	45	88	59	14	100	85
	71	33	66	64	79	62	14	38	53	74
3	87	49	97	81	86	2	82	20	83	60
	61	1	36	21	67	43	18	72	19	35
4	26	43	38	54	64	3	17	74	8	6
	37	48	34	24	5	69	39	25	90	98
5	91	5	7	30	70	25	13	63	67	75
	49	75	29	76	7	93	100	95	82	23
6	95	36	29	96	56	61	19	24	89	73
	26	63	2	59	40	60	10	73	85	3
7	44	15	40	16	72	39	65	52	93	4
	9	6	80	86	20	54	84	88	11	42
8	76	1	84	98	92	21	11	9	90	50
	52	81	15	50	41	99	91	77	78	28
9	71	41	27	68	57	80	10	99	62	55

CORRELATION BETWEEN GRAIN AND PADDY

The last column of Table VII gives the coefficient of correlation between yield of grain and yield of straw for variations due to blocks, varieties and residual (error).

The high correlation of $+0\cdot9164$ due to blocks indicates that blocks with large yields of grain also have large yields of straw, and blocks with low yields of grain have low yields of straw. This shows that the influence of soil fertility on the yield of both grain and straw is working in the same direction. That is, the yield of both grain and straw is greater in better type of soil which is just what is to be expected.

The inter-varietal correlation or the correlation between the mean yields of grain and of straw for the varieties is only +0·1299 which is insignificant at the 5 per cent level. It will be seen from the accompanying scatter diagram (Fig. 1) that there is little or no tendency towards clustering in the points. This shows that a variety having a high yield of grain does not necessarily have a high yield of straw. In fact, on an average among

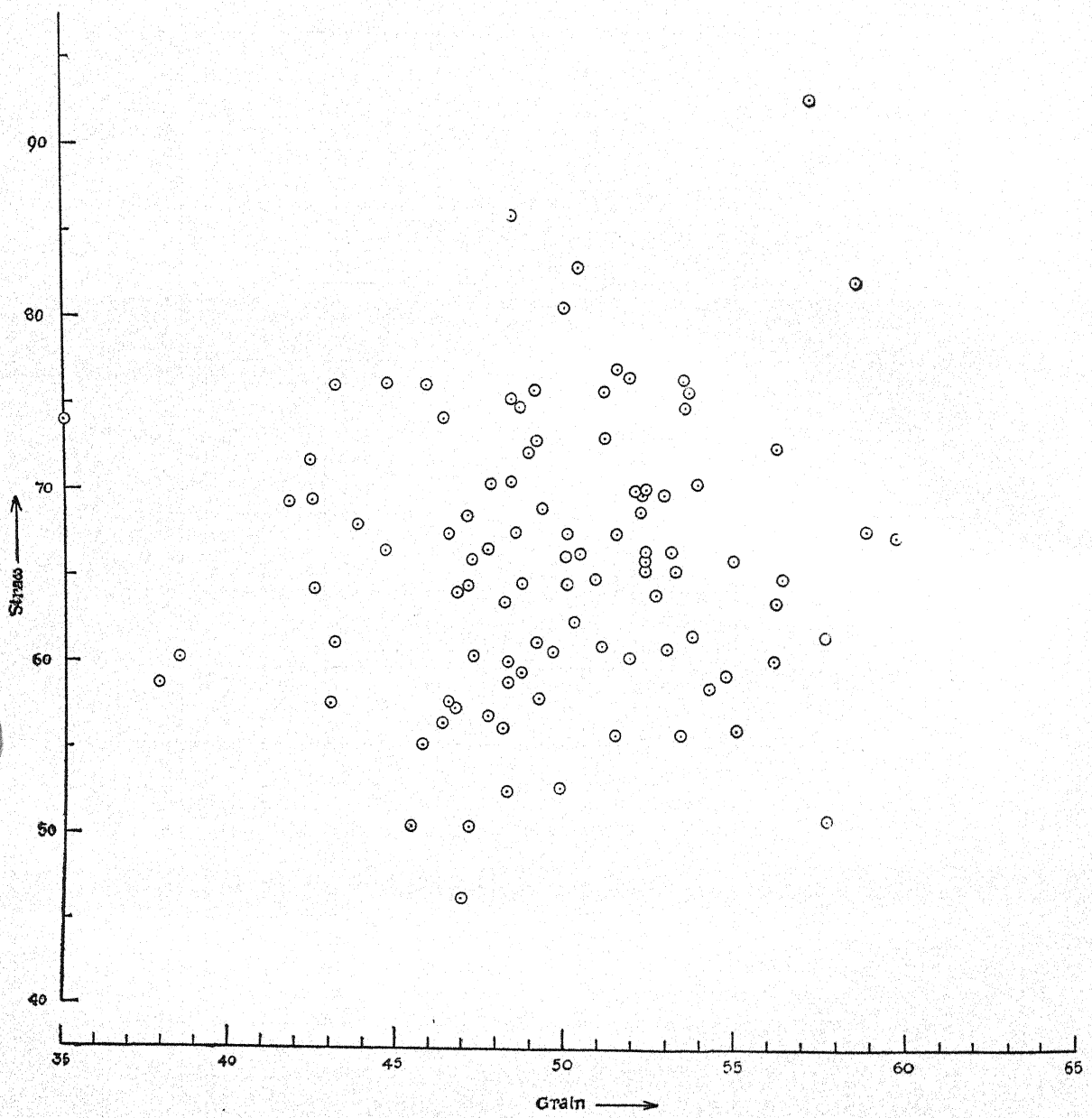


FIG. 1. Scatter diagram of the mean yields of grain and straw of the one hundred varieties

varieties giving high yields of grain there will be all kinds of yields of straw, high, medium and low. This clearly brings out the danger of confining our attention to a single character, say, the yield of grain, in pre-selection field trials.

The residual (error) correlation is +0·6559 which is significant at the one per cent level. This gives the correlation between yield of grain and of straw of individual plots after correcting for effects of both blocks and varieties. The significant correlation shows that the uncontrolled factors, such as differences in fertility from plot to plot, exert their influence in the same direction on both grain and straw.

Joint comparison of yields

Before concluding we shall make a few preliminary observations regarding a comparison of the varieties jointly on the basis of yields of both grain and straw.

If we attach the same importance to both grain and straw (which, of course, is not really justified from the agricultural or economic point of view), a rough way of assessing the relative value of the crop as from both the two characters, will be to add the two ranks, and arrange the varieties in accordance with their combined ranks. If there had been perfect correlation between the two characters, the combined ranks would have taken the values 2, 4, 6 .....200. In our case the combined rank shown in Table X starts from 7 and ends with 196, with repetitions at some of the values. Thus rank 7 is shared by the varieties 18 and 97. Variety 18 stood first also in the ranking for straw yield; but variety 14, which stood first in the ranking for grain yield, stands low in the combined ranking, due to its poor straw yield.

Table X

Sum of the ranks of grain and straw yields

i / j	0	1	2	3	4	5	6	7	8	
0	98	66	85	98	136	87	101	67	92	69
1	30	130	126	65	79	104	75	85	110	116
2	142	60	61	126	132	156	116	31	196	177
3	158	82	163	145	165	64	96	58	136	134
4	87	44	74	75	131	46	35	146	27	41
5	128	53	41	54	75	94	52	88	157	173
6	144	111	58	172	63	154	119	119	171	96
7	70	78	42	75	112	99	75	125	178	7
8	85	7	164	184	112	75	95	97	101	92
9	123	122	42	118	98	179	101	176	140	83

TABLE XI

Relative total money value of grain and straw (figures in parenthesis give the rankings)

i / j	0	1	2	3	4	5	6	7	8	9
0	69·70 (11)	67·19 (30)	64·28 (52)	64·39 (50)	61·55 (69)	64·71 (48)	62·48 (62)	65·54 (42)	67·62 (22)	67·63 (21)
1	71·98 (5)	56·57 (92)	58·58 (86)	69·30 (12)	64·56 (49)	64·08 (53)	66·87 (35)	67·13 (32)	63·80 (54)	62·15 (64)
2	61·29 (70)	67·35 (28)	67·45 (26)	57·49 (90)	69·15 (15)	60·37 (79)	62·73 (60)	70·12 (7)	51·37 (98)	55·48 (96)
3	60·01 (80)	66·33 (39)	59·60 (82)	61·06 (74)	59·17 (83)	67·18 (31)	66·91 (34)	67·06 (33)	61·73 (67)	61·13 (73)
4	63·67 (55)	74·37 (3)	66·33 (38)	67·44 (27)	61·95 (66)	68·38 (18)	69·86 (9)	60·42 (78)	70·11 (8)	68·33 (19)
5	63·64 (56)	67·50 (25)	68·48 (17)	68·09 (20)	61·05 (75)	63·06 (58)	67·62 (23)	66·60 (37)	56·48 (93)	51·63 (97)
6	60·99 (76)	61·98 (65)	67·54 (24)	58·48 (87)	70·57 (6)	56·47 (94)	51·27 (99)	57·95 (88)	58·61 (85)	66·22 (40)
7	68·99 (16)	64·72 (47)	73·56 (4)	64·86 (45)	64·36 (51)	63·20 (57)	69·80 (10)	61·58 (68)	57·73 (89)	76·38 (2)
8	69·27 (13)	77·37 (1)	59·05 (84)	56·30 (95)	65·59 (41)	64·97 (43)	62·34 (63)	61·20 (71)	67·27 (29)	64·81 (46)
9	62·51 (61)	61·17 (72)	69·19 (14)	62·73 (59)	64·96 (44)	50·68 (100)	59·62 (81)	56·91 (91)	60·67 (77)	66·62 (36)

From the economic point of view the procedure of using the joint rank for grain and straw yields is unsatisfactory, for the money returns from equal weights of grain and straw are quite different. A better plan is to use the total money return of the crop for both paddy and straw taken together. For example, for the crop under consideration, we find that Rs. 2 and As. 7 may be taken as the average price of one maund of grain and of one maund of straw respectively ; and we can reduce the yield of straw to equivalent quantities of grain by using the multiplier 7/32.

The mean yield of straw measured on this new scale is added to the mean yield of grain of each variety to assess the total money value of the yields of grain and straw. These are given in Table XI in which the ranks are written in parenthesis. Varieties 18 and 97 now stand differentiated, as first and second, though there was a tie between them for the first place in the ranking given in Table X. Variety 14, which stood low in Table X in spite of having the highest yield in grain, stands third in importance according to the assessment made in Table XI.

While judging the superiority of one variety to another, ranks are, however, not quite satisfactory, and rigorous tests of significance should be used. We can do this for the values given in Table XI by using an analysis of variance of the ' money value ', namely, of the variable.

$$M = X + \tfrac{7}{32} Y \qquad (5)$$

where X = yield of grain and Y = yield of straw. The relevant data are given in Table XII. The sum of squares in any line of this table is obtained by multiplying by $(7/32)^2$, (7/16) and (1) respectively the sum of squares of straw, sum of products, and sum of squares of grain, of the corresponding line of Table VII.

TABLE XII

Analysis of variance of total money value of grain and straw

——	D. F.	Sum of squares	Variance	Ratio of variances	
				Observed	Expected 1 per cent
Blocks	39	24528·5769	628·94		
Varieties . . .	99	9566·5567	96·63	2·54	<1·88
Error	261	9937·3552	38·07		
Total .	399	44032·4888			

The ratio of variances for M is highly significant, showing the high variation in the money value of the different varieties. The standard error per plot of the money value is 6·1705. The standard error of the difference between any two values occurring in the same row or column of Table XI is 4·576 and the critical differences at 5 per cent and 1 per cent levels are respectively 9·01 and

11·90. The standard error of the difference between any two values of Table XI not occurring in the same row or column is 4·780 and the critical differences at the 5 per cent and 1 per cent levels are respectively, 9·42 and 12·43. With the help of these critical values it is now possible to use tests of significance for comparing the money values of any two varieties.

Summary

A new method of analyses of variance and covariance has been discussed, with the help of actual experimental data of a quasi-factorial experiment on paddy with one hundred varieties arranged in a square lattice design ; and it has been shown that the new procedure will considerably reduce the computational labour.

From the analysis of covariance it has been found that there is little or no inter-varietal correlation between mean yield of grain and mean yield of straw of the different varieties. This shows the need of taking into consideration more than one economic character of the plant, in this case, for example, the yield of both grain and straw in pre-selection trials.

For the purpose of grading the varieties it is clearly desirable to use a scale which will take into consideration both grain and straw. Two methods, namely, (1) the sum of the separate ranks of the two characters, and (2) the money return from both grain and straw have been briefly discussed for purposes of illustration. The varieties were found to be significantly differentiated with regard to the money return.

Acknowledgements

Our sincere thanks are due to Mr S. C. Chakravarty, Rice Research Officer-Chinsurah Farm, Bengal, who was in charge of the field experiment, for supplying us with the primary material.

Our thanks are due to Mr Topobikash Basu, M.Sc., for assistance in computations ; and to the Imperial Council of Agricultural Research for financing a portion of the expenses.

Note added 11 December 1939

We are grateful to Rao Bahadur M. Vaidyanathan for having drawn our attention to a short paragraph on page 125 of the revised edition (1937) of C. H. Goulden's *Methods of Statistical Analysis* in which the author gives an expression for the sum of squares of varieties alternative to the one given by Yates. The expression used by us is entirely different and applicable to the wider class of ' Partially Balance Incomplete Block Designs ', dealt with in this paper.

References

Bose, R. C. and Nair, K. R. (1939). *Sankhya* **4**, 337-72

Lawley, D. N. (1938). *Biometrika* **30**, 180-7

———— (1939). *Biometrika* **30**, 467-9

Roy, S. N. (1939, 1). *Science & Culture* **5**, 131-2

———— (1939, 2). *Sankhya* **4**, 381-96

Yates, F. (1936, 1). *J. Agric. Sc.* **26**, 424-55

———— (1936, 2). *Ann. of Eugencis* **7**, 121-40

APPENDIX

Random No.	Name of strain		Random No.	Name of strain	
00	Kalma	107/36	50	Harimai	1180/34
01	Maula	1332/36	51	Bankumari	1031/36
02	Jatakalma	389/33	52	Uttarekalma	386/33
03	Baktulsi	928/36	53	Karticsail	1350/36
04	Rupsail	849/36	54	Rangi	475/32
05	Ahamsail	1129/36	55	Kalakartic	135/32
06	Madhumalati	1515/36	56	Tengra	1541/36
07	Kanakchur	1221/36	57	Nona	251/32
08	Dudkalma	144/36	58	Jhingasail	220/36
09	Ramsail	1283/36	59	Kamalbhog	1127/36
10	Ailsail	1092/36	60	Kamalbhog	1532/36
11	Gopalbhog	916/36	61	Sundarsail	1346/36
12	Latamagurasail	1357/36	62	Peswari	1083/36
13	Baskamalbhog	1342/36	63	Jhingasail	221/36
14	Dudkalma	191/36	64	Kalma	94/36
15	Kartikbalam	1597/36	65	Luchai 15	945/36
16	Mugaibalam	1547/36	66	Tengrasylhet	940/36
17	Agniswar	1712/36	67	Dudkalma	366/33
18	Lalkalma	158/36	68	Kamanisail	938/36
19	Bankumari	1355/36	69	Kamalbhog	1607/36
20	Sarunagra	284	70	Karticbalam	1594/36
21	Kalma	112/36	71	Dudkalma	85/36
22	Peswari	1139/36	72	Jhingasail	275/36
23	Kalamkati	47/35	73	Seetasail	833/36
24	Mota	1690/36	74	Brindabansail	1219/36
25	Jhingasail	215/36	75	Tengrasylhet	1324/36
26	Gangajal	1709/36	76	Mahipal	1194/34
27	Harimai	1207/36	77	C-O 1	(1171/36)
28	Seetasail	496/32	78	Mausal 239	..
29	Lalkalma	176/32	79	Nagra 40	322/33
30	Chamarmani	874/36	80	Bachaibalam	1173/36
31	Kalma	95/36	81	Chamarmani	876/36
32	Harimai	1211/36	82	Baktulsi	915/36
33	Localnagra	..	83	Algorasail	1118/36
34	Kalma	182/36	84	Rupsail	196/33
35	T 31 (Pusa)	..	85	Ramsail	1503/36
36	Bakchur	..	86	Sitasail	830/36
37	C-O 1	..	87	Baktulsi	914/36
38	Nagra 100	266/32	88	Dudkalma	133/36
39	Jatakalma	401/33	89	GEB 24	..
40	SC 54/10	(1326/36)	90	Bhasamanik	..
41	Peswari	1096/36	91	Metekalma	183/32
42	Kamalbhog	1523/36	92	Dudkalma	166/36
43	Rudin	1531/36	93	Baktulshi	960/36
44	T 24 (Pusa)	..	94	Magurasail	1519/36
45	Nagra	126 (308/33)	95	T 52 Pusa	..
46	Patharkuchi	1273/36	96	Seetasail	834/36
47	Baskamalbhog	1036/36	97	Auspapri	1172/36
48	Nagra	65/5 (262/32)	98	Pubebalam	1599/36
49	Sitasail	815/36	99	Harimai local	1110/36

THE ANALYSIS OF SIMPLE NON-SYMMETRICAL EXPERIMENTS *

BY

P. V. KRISHNA IYER

Imperial Agricultural Research Institute, New Delhi

(Received for publication on 19 September 1939)

INTRODUCTION

THE analyses of symmetrical experimental designs, viz. Latin squares, randomized blocks, incomplete symmetrical randomized blocks, etc., are simple and fairly well-known. When these layouts happen to become asymmetrical due to some cause which is beyond the control of the experimentern the analysis becomes complicated and can be done only by the actual application of the principle of least squares to the data. Methods for the analyses of experiments involving a number of missing plots have already been given by Yates. The method given so far stops with the analysis of variance table which simply shows whether there is any difference between the various varieties (or treatments) on the whole. To obtain further information regarding the different varieties (or treatments), it is necessary to calculate the standard error of the various mean differences, which is very laborious when there are a large number of varieties with different replications. The present paper indicates how it is possible to obtain more information by dividing the varieties into different groups by the application of the principle of least squares a second time in such a way as to enable us to split the total sum of squares for varieties into sum of squares between groups and within groups of the varieties.

It must be clearly understood that by giving this method of analysis for asymmetrical experiments, it is not at all meant that experimenters can have their experiments in any way they choose. Symmetrical experiments are more efficient than non-symmetrical ones. But whenever experiments become asymmetrical due to unforeseen circumstances, the method outlined below can more advantageously be used for obtaining information on the different varieties.

MATERIAL

The material used for illustrating the method of analysis consists of a varietal yield trial with nine varieties conducted for the Imperial Economic Botanist at the Government Agricultural Farm, Bahraich (U. P.). The details of the experiment are given below :

Varieties tested . .	P. 4, P. 12, P. 52, P. 80-5, P. 111, P. 120, P. 165, C. 13, Pb. 518.
	(P stands for Pusa, Pb. for Punjab and C for Cawnpore)
Layout . . .	9 × 6 randomized blocks
Ultimate plot size . .	46 ft. × 12 ft. or 1/80 acre (approximately)

* Read before the Indian Science Congress held in Madras, 1940

General manuring	Sannhemp green manure
Sowing date	26 October 1937
System of sowing	Behind *desi* plough in furrows 8 in. to 9 in. apart
Irrigation given	One, 12 to 13 November 1937
Harvesting date	22 to 28 March 1938

Plan of the experiment showing the yield of grain per plot in pounds

I	...	...	G 15·50	F 12·25	D 24·75	B 24·75	E 15·75	H 31·25	A 19·00
II	...	...	...	C 27·00	H 33·00	A 16·25	G 17·50	F 19·25	E 23·75
III	...	...	...	D 24·50	G 18·75	H 27·00	E 20·75	C 27·75	B 28·75
IV	...	...	...	A 24·50	H 31·00	F 16·00	I 34·25	B 30·00	D 18·25
V	...	...	...	H 32·00	...	G 18·25	E 21·25	D 21·50	F 17·50
VI	...	...	F 15·00	G 16·00	C 21·25	I 23·75	D 17·00	E 18·75	B 23·75

The yields from plots left blank were very poor and hence have been omitted from the statistical analysis. A, B, C, D, E, F, G, H and I denote P. 4, P. 12, P. 52, P. 80-5, P. 111, P. 120, P. 165, C. 13 and Pb. 518 respectively.

METHOD OF ANALYSIS

Constants a, b, c, d, e, f, g, h and i ; b_1, b_2, b_3, b_4, b_5 and b_6 representing the varietal and the block effects respectively are fitted to the data by applying the principle of least squares. It can easily be shown that the equations for determining the above constants are

Set 1 .

$$\begin{cases} 7m+7b_1+a+b+d+e+f+g+h = 143\cdot25 \text{ (Total for block I)} \\ 6m+6b_2+a+c+e+f+g+h = 136\cdot75 \text{ (,, ,, ,, II)} \\ 6m+6b_3+b+c+d+e+g+h = 147\cdot50 \text{ (,, ,, ,, III)} \\ 6m+6b_4+a+b+d+f+h+i = 154\cdot00 \text{ (,, ,, ,, IV)} \\ 5m+5b_5+d+e+f+g+h = 110\cdot50 \text{ (,, ,, ,, V)} \\ 7m+7b_6+b+c+d+e+f+g+i = 135\cdot50 \text{ (,, ,, ,, VI)} \end{cases}$$

Set 2 .

$$\begin{cases} 3m+3a+b_1+b_2+b_4 = 59\cdot75 \text{ (Total for variety A)} \\ 4m+4b+b_1+b_3+b_4+b_6 = 107\cdot25 \text{ (,, ,, ,, B)} \\ 3m+3c+b_2+b_3+b_5 = 76\cdot00 \text{ (,, ,, ,, C)} \\ 5m+5d+b_1+b_3+b_4+b_5+b_6 = 106\cdot00 \text{ (,, ,, ,, D)} \\ 5m+5e+b_1+b_2+b_3+b_5+b_6 = 100\cdot25 \text{ (,, ,, ,, E)} \\ 5m+5f+b_1+b_2+b_4+b_5+b_6 = 80\cdot00 \text{ (,, ,, ,, F)} \\ 5m+5g+b_1+b_2+b_3+b_5+b_6 = 86\cdot00 \text{ (,, ,, ,, G)} \\ 5m+5h+b_1+b_2+b_3+b_4+b_5 = 154\cdot25 \text{ (,, ,, ,, H)} \\ 2m+2i+b_4+b_6 = 58\cdot00 \text{ (,, ,, ,, I)} \end{cases}$$

For practical purposes the formation of the above equations is easy. The left hand side of set 1 is the sum of least square estimates of the different varieties in blocks I, II, ...VI *plus* the respective block

effects ; that of set 2 is the sum of least square estimates of the varieties multiplied by the number of times it occurs *plus* the effects of the blocks in which each variety falls, m is the general mean of all the plots and $b_1, b_2, \ldots\ldots b_6$ have been so selected that

$$7b_1+6b_2+6b_3+6b_4+5b_5+7b_6=0$$

By virtue of the above relation we will also find that

$$3a+4b+3c+5d+5e+5f+5g+5h+2i=0$$

Eliminating m, a, b, c, d, e, f, g, h and i from set 2 by the aid of set 1 we get

Set 3 .

$$\left\{\begin{array}{rrrrrrrr} 325b_1- & 68b_2- & 63b_3- & 71b_4- & 60b_5- & 63b_6= & -526\cdot75 \\ -68b_1+ & 272b_2- & 56b_3- & 44b_4- & 48b_5- & 56b_6= & 444\cdot00 \\ -63b_1- & 56b_2+ & 277b_3- & 39b_4- & 48b_5- & 71b_6= & 363\cdot25 \\ -71b_1- & 44b_2- & 39b_3+ & 259b_4- & 36b_5- & 69b_6= & 613\cdot25 \\ -5b_1- & 4b_2- & 4b_3- & 3b_4+ & 20b_5- & 4b_6= & 26\cdot00 \\ 7b_1+ & 6b_2+ & 6b_3+ & 6b_4+ & 5b_5+ & 7b_6= & 0 \end{array}\right.$$

Solving the above set of equations we get

$b_1=-1\cdot16623$, $b_2=1\cdot37377$, $b_3=0\cdot96102$
$b_4=1\cdot74759$, $b_4=1\cdot11208$, $b_6=3\cdot12729$

Substituting these values in the 1st set of equations, we find

$a=-3\cdot09990$, $b=4\cdot84387$, $c=3\cdot23264$
$d=-1\cdot07029$, $e=-2\cdot14553$, $f=-6\cdot35285$
$g=-4\cdot99553$, $h=7\cdot67949$, $i=7\cdot32499$

The reduction in the sum of squares due to constants fitted is

$$b_1B_1+b_2B_2+b_3B_3+b_4B_4+b_5B_5+b_6B_6+aT_a+bT_b+cTc+dTd+eT_e+fT_f+gT_g+hT_h+\\+iT_i,$$

Where $B_1, B_2, \ldots\ldots B_6$; $T_a, T_b, \ldots\ldots T_i$ are the blocks and the treatment totals respectively, and is equal to 1053·811.

Sum of squares for varieties alone is=1053·811—sum of squares for blocks calculated in the usual way, i.e.=1053·811—184·994=868·817.

We can now draw up the analysis of variance table after calculating the total sum of squares in the usual way.

Analysis of variance

Variance due to	Degrees of freedom	Sum of squares	Mean square
Blocks	5	184·994	..
Varieties	8	868·817	108·602
Error	23	173·014	7·522
Total	36	1226·825	

Before we proceed further, let us get the least square estimates of the various varieties. They are

a+m, b+m, ...i+m.

A=19·26496	B=27·20873	C=25·59750
D=21·29457	E=20·21933	F=16·01201
G=17·36933	H=30·04435	I=29·68985

From the analysis of variance table, we note that the differences among the various varieties are on the whole significant. Further information regarding the varieties can be had either by examining the mean differences with the help of their standard errors or by grouping the varieties into different classes which are possibly significantly different from one another. In non-symmetrical experiments it will be found that the latter method is more convenient and involves less labour. In our example, examining the least square estimates,* it looks that the nine varieties can be classified into four groups as follows :—

A=D=E. I ; B=C. II ; F=G. III ; H=I. IV

Our object now is to see whether there is any significant difference between and within these groups. For this, fit constants x, w, y and z to represent these groups to the original data, i.e. m+x, m+w, m+y and m+z are the least square estimates of groups I, II, III and IV respectively on the assumption that there is no difference between the various varieties comprising the groups. The equations for determining the constants x, w, y and z ; b_1, b_2, b_3, b_4, b_5 and b_6 are

$$\left.\begin{aligned} 7m+7b_1+3x+w+2y+z &= 143\cdot25\\ 6m+6b_2+2x+w+2y+z &= 136\cdot75\\ 6m+6b_3+2x+2w+y+z &= 147\cdot50\\ 6m+6b_4+2x+w+y+2z &= 154\cdot00\\ 5m+5b_5+2x+2y+z &= 110\cdot50\\ 7m+7b_6+2x+2w+2y+z &= 135\cdot50 \end{aligned}\right\} \quad (1);$$

$$\left.\begin{aligned} 13m+13x+3b_1+2b_2+2b_3+2b_4+2b_5+2b_6 &= 266\cdot00\\ 7m+7w+b_1+b_2+2b_3+b_4+2b_6 &= 183\cdot25\\ 10m+10y+2b_1+2b_2+b_3+b_4+2b_5+2b_6 &= 166\cdot00\\ 7m+7z+b_1+b_2+b_3+2b_4+b_5+b_6 &= 212\cdot25 \end{aligned}\right\} (2)$$

As before, m is the general mean of all the plots, and b_1, b_2,.....b_6 are so selected that

$$7b_1+6b_2+6b_3+6b_4+5b_5+7b_6=0.$$

It may be noted that for practical purposes (1) is obtained from set 1 by putting a=d=e=x ; b=c=w ; f=g=y ; h=i=z and (2) from set 2 by adding up the equations involving a, d, e ; b, c ; f, g ; h, i ; and putting in the final equations a=d=e=x, b=c=w, f=g=y, h=i=z.

Eliminating b_1, b_2,.....b_6 we get

$$\begin{aligned} 13x+\ 7w+10y+\ 7z &= 827\cdot50\\ 1331x-\ 24y-\ 12z &= 26401\cdot50\\ -35x+1355w-\ 5y-\ 20z &= 34516\cdot25\\ -59x-\ 20w-29y+1403z &= 39802\cdot75 \end{aligned}$$

Solving the above equations

x=—1·95783, w=4·13921, y=—5·66257, z=7·58611

Substituting the values in (1)

b_1=—1·11868 b_2=1·01272 b_3= 1·17075

b_4=1·67960 b_5=1·26607 b_6=—3·09683

Reduction in the sum of squares due to the four groups and the blocks is 1037·756 and is given by $xT_x+wT_w+yT_y+zT_z+b_1B_1+.....b_6B_6$ where T_x, T_w, T_y and T_z are the four totals for the respective groups. Sum of squares due to blocks alone already calculated is 184·994. Hence the sum of squares between groups=1037·756—184·994=852·762. Sum of squares within groups=868·817—852·762=16·055. Now we can draw up the final

*This can be *roughly* done by the aid of S. E. for M_d calculated in the usual way on the available number of replications.

analysis of variance table which gives almost all the information regarding the various varieties.

Analysis of variance

Variance due to		Degrees of freedom	Sum of squares	Mean squares
Blocks		5	184·994	
Varieties	Between groups	3	852·762	284·254
	Within groups	5	16·055	3·211
Residual error		23	173·014	7·522
	Total	36	1226·825	

The above analysis of variance table shows that the differences between the four groups are highly significant. But the variance within groups is not significant. Thus it will be seen that the nine varieties can be divided into four groups which are significantly different.

SUMMARY

It has been shown that in the case of non-symmetrical experiments by applying the principle of least squares twice, it is possible to extract most of the information regarding the different varieties (or treatments) of the experiment. The first application gives the total sum of squares due to varieties. The subsequent application is so done as to classify the different varieties into groups which are significantly different from one another.

REFERENCES

Yates, F. (1933).—*Emp. J. Expt. Agric.* **1**, 129-42

——— (1934).—*J. Amer. Stat. Associ.* **28**, 51-66

——— (1936).—*Jour. Agric. Sci.* **26**, 301-15

A SUPPLEMENTARY NOTE ON THE ANALYSIS OF 3^3 AND 3^4 DESIGNS (WITH THREE-FACTOR INTERACTIONS CONFOUNDED) IN FIELD EXPERIMENTS IN AGRICULTURE

BY

S. SUBRAMONIA IYER, M.A., F.S.S.

Imperial Council of Agricultural Research, New Delhi

(Received for publication on 10 July 1940)

IN the paper on the analysis of 3^3 and 3^4 designs published in a recent issue of this Journal (Vol. X, part II, April 1940, pp. 213-36) the method of calculation of the partially confounded three-factor interactions requires a small correction. In Table VI-*a* it was assumed that in order to get the corrected totals W', X', etc., it was sufficient to subtract J_1, J_2 and J_3 (Table V-*a*) from W_1, W_2 and W_3 respectively and so on. But, on examination, the degrees of freedom confounded are found to be as follows :—

(1), (2).....(9) refer to block Nos. (Table I-*a*).

I's, *J*'s, *R*'s and *C*'s refer to the respective diagonal, row and column totals in Table V-*a*.

ABC

Replication I	Replication II	
W_1	X_1	(1)+(6)+(8) (J_1)
W_2	X_2	(3)+(5)+(7) (J_3)
W_3	X_3	(2)+(4)+(9) (J_2)

ABD

Replication I	Replication II	
Y_1	Z_1	(1)+(5)+(9) (I_1)
Y_2	Z_2	(3)+(4)+(8) (I_3)
Y_3	Z_3	(2)+(6)+(7) (I_2)

ACD

Replication I	Replication II	
Z_1	W_1	(1)+(4)+(7) (R_1)
Z_2	W_2	(3)+(6)+(9) (R_3)
Z_3	W_3	(2)+(5)+(8) (R_2)

BCD

Replication I	Replication II	
X_1	Y_1	(1)+(2)+(3) (C_1)
X_2	Y_2	(4)+(5)+(6) (C_2)
X_3	Y_3	(7)+(8)+(9) (C_3)

Therefore in Table VI-*a*, for *ABC*, we have to subtract J_3s from W_2 and X_2 and J_2s from W_3 and X_3 ; for *ABD*, I_3s from Y_2 and Z_2 and I_2s from Y_3 and Z_3, and for *ACD*, R_3s from Z_2 and W_2 and R_2s from Z_3 and W_3.

There is no interchange in the case of *BCD*. Thus for *ABC* (W') the working sheet will appear as follows :—

ABC

	1	2	3	
W	2012	2011	2228	
	1363	1259	1316	(J_1, J_2 and J_3 of Table V-*a*)
W'	649	752	912	
instead of	649	695	969	and so on.

The totals thus obtained have been checked by calculating them independently from the replication in which the particular interaction is not confounded.

On the basis of these new totals the sum of squares in the final table of analysis of variance (Table X-*a*) corresponding to :—

ABC (W')	will be	1300·96	instead of	2217·18
ABC (X')	„	4819·58	„	12327·11
ABD (Y')	„	2462·29	„	4593·85
ABD (Z')	„	2046·69	„	5909·73
ACD (W')	„	185·21	„	30680·40
ACD (Z')	„	4048·23	„	954·74
and remainder		78237·91	„	36417·86

The main point to be emphasized is that while applying the general rule regarding the block totals for estimating the unconfounded parts, it is important to see actually in any particular design which totals correspond to W_1, W_2, W_3 and so on and not subtract J_1, J_2, J_3 of the block totals for instance from the respective W_1, W_2 and W_3. In other words, for each design of the type considered, it is essential to see which block totals give the comparisons of the confounded degrees of freedom in each replication. This can easily be done with the help of Table 43 in Yate's [1937] bulletin on the 'Design and analysis of factorial experiments'.

I am thankful to Mr P. H. Carpenter of the Tocklai Tea Experimental Station (Assam) for bringing this point to my notice.

REFERENCE

Yates, F. (1937). *Imperial Bureau of Soil Science Technical Communication No.* 35

NOTE

NOTIFICATION NO. F. 1-9 (3)/40-A, DATED THE 29TH MAY 1940, ISSUED BY THE GOVERNMENT OF INDIA IN THE DEPARTMENT OF EDUCATION, HEALTH AND LANDS

THE following Order issued by the Ministry of Agriculture and Fisheries, London, called ' The Importation of Plants (Amendment) Order of 1940 ', is published for general information :—

STATUTORY RULES AND ORDERS 1940 No. 544

DESTRUCTIVE INSECT AND PEST, ENGLAND

THE IMPORTATION OF PLANTS (AMENDMENT) ORDER OF 1940 DATED APRIL 10, 1940

(D. I. P. 607)

The Minister of Agriculture and Fisheries, by virtue and in exercise of the powers vested in him under the Destructive Insects and Pests Acts, 1877 to 1927 (a), and of every other power enabling him in this behalf, orders as follows :—

Modification of the Importation of Plants Order of 1939

1. The Importation of Plants Order of 1939 (b) (hereinafter referred to as ' the principal Order ') is hereby modified in the manner provided by this Order.

Application to Spain of Articles 5, 6 and 7 of the principal Order and of the Third Schedule thereto

2. Article 5 (5), Article 6 (1) and (3), Article 7 (1) and (3) of the principal Order and Form A in the Third Schedule thereto shall be read and have effect as if in addition to the countries specifically mentioned Spain were mentioned therein ; and in respect of any plants potatoes raw vegetables and cider apples grown in Spain any certificate required by any of the said Articles shall be a certificate of a duly authorised Official of the Spanish Phytopathological Service.

Amendment of Article 6 of the principal Order

3. For Article 6 (2) of the principal Order shall be substituted :—

' (2) The landing in Englad nor Wales between the twenty-first day of April and the thirtieth day of September in any year of any raw vegetables grown in Belgium, Germany, Luxemburg, or the Netherlands is hereby prohibited unless in the case of a consignment landed between the twenty-first day of April and the thirty-first day of May in any year each consignment is accompanied by a certificate of origin vise by a competent authority in the country of origin stating the country and place where

(a) 40 and 41 Vict. C. 68, 7 Edw. 7. C. 4 and 17 and 18 Geo. 5. C. 32
(b) S. R. and O. 1939 (No. 532) I. P. 635

the raw vegetables were grown ; and in the case of a consignment landed between the first day of June and the thirtieth day of September in any year each consignment is accompanied by a certificate of a duly authorised Official of the Belgian, German, Luxemburg or Dutch Phytopathological Service (as the case may be) in the Form A or the Form B set out in the Third Schedule to this Order.'

Commencement

4. This Order shall come into operation on the twenty-first day of April, nineteen hundred and forty.

Short Title and Construction

5. This Order may be cited as the Importation of Plants (Amendment) Order of 1940 and shall be read as one with the principal Order, and the principal Order and this Order may be cited together as the Importation of Plants Orders of 1939 and 1940.

REVIEW

Vegetative Propagation of Tropical and Sub-tropical Plantation Crops. By G. St. Clair Feilden and R. J. Garner. *Technical Communication 13 of the Imperial Bureau of Horticulture and Plantation Crops, East Malling, Kent, England*, 1940, pp. 99, bibl. 284, 3*s*. 6*d*.

WHEN in 1936 the Imperial Bureau of Fruit Production issued a technical communication dealing with the vegetative propagation of some 100 fruit varieties grown in the tropics and sub-tropics, it was not without misgivings as to the number of persons likely to be interested. That such fears were unwarranted was quickly shown by the demand on issue. This was immediate and so considerable as to necessitate the reproduction of the publication in the following year.

The present work by the renamed Bureau, which deals, appropriately enough, with the vegetative propagation of some 55 plantation crops, should form a useful companion volume. The help of technical experts has been invoked for adequate treatment of such major crops as rubber, coffee, cacao, etc., while the foreign literature has been thoroughly combed for details of propagation of the less familiar, but nevertheless, important crops.

One feature of the previous work which commended it also to workers in temperate regions is retained and considerably enlarged. That is the section devoted to methods used in vegetative propagation. The descriptions there are supported by simple, clear line drawings of some 17 types of graft and 7 types of budding commonly used in vegetative propagation.

In addition, tropical workers will be glad of the account and illustrated detail of the construction of loosely-woven potting baskets which have been found so useful a substitute for pots in nursery work in the tropics.

For those who wish to study originals a list of references immediately follows the discussion on the propagation of each particular crop.

GIPD—93 ICofAR—4-9-40—750.

ORIGINAL ARTICLES

THE PROBLEM OF INTER-PROVINCIAL PLANT QUARANTINES IN INDIA *

BY

G. WATTS PADWICK

Imperial Mycologist, Imperial Agricultural Research Institute, New Delhi

AND

B. N. UPPAL

Plant Pathologist to the Bombay Government, Agricultural College, Poona

(Received for publication on 2 January 1940)

CROP CATEGORIES IN INDIA

INDIA is frequently referred to as a sub-continent, a description it acquires by virtue of its separation from the rest of Asia on its northern boundary by the Himalayas. There are land-passes of fairly low altitudes at the eastern and western extremities of the range, but in general the mountains prevent the free passage of goods almost as effectively as the sea. The rest of India is divided into two main areas, the northern plains, and the central and southern plateau. In the southern plateau there are only a few high elevations. The Western Ghats rise to an elevation of about 3,000 ft. with peaks of nearly 9,000 ft. The Eastern Ghats have an average elevation of only about 1,500 ft., with much lower peaks.

The plains of northern India have a climate divisible into four distinct seasons ; the cold weather, from November or December (according to locality) to March or April ; a period of extreme heat following ; the monsoon period of lesser heat and higher humidity ; and the post-monsoon period of September and October, with a second rise in temperature accompanied by a gradual fall in humidity. Southern India's climate, at least in the lower altitudes, is a mild modification of that of the plains, the hot weather starting much sooner but never reaching the same heights, and the cold weather being modified. The Himalayas and the southern hill ranges contain considerable areas of temperate climate, isolated from one another by areas of lower elevation with higher summer temperatures. Thus, for instance, the Nilgiris in Madras, Mahabaleshwar in Bombay, Kodaikonal and Nandi Hills (Madras), the Eastern Ghats in Madras and Orissa, the Vindhyas in Central India and the Central Provinces, are all separated by wide expanses of low-lying lands. In these hilly areas, temperate crops, notably fruits and vegetables, are grown. Again, in the Himalayas there are substantial areas devoted to similar crops in Quetta, Baluchistan, North-West Frontier Province, Kashmir, Kulu in the

*This paper was originally submitted for the Fourth Imperial Mycological Conference, to have been held in London in September 1939. The Conference was cancelled. The anticipated paper had, however, aroused interest outside India, and was submitted for publication here at the suggestion of the Director of the Imperial Mycological Institute, Kew.

Punjab, Ramgarh and Chaubattia in the United Provinces, and Sikkim, all isolated from one another by long distances although connected by a common elevation level.

In addition to separation by mountain areas, there is another form of barrier in India, namely desert area. Actually there is only one such important area, the Rajputana desert, an area of extremely high temperatures and low rainfall in which the crops are mainly those which can grow on the small amount of residual moisture resulting from the meagre monsoon showers.

In brief, then, India consists of one large plain growing tropical or sub-tropical crops, cut up in many parts of the south by isolated hill ranges, and bounded on the north by the huge range of the Himalayas. It is like an ocean dotted with islands, the ' ocean ' being the area of low elevation having an almost continuous connection throughout, the ' islands ' being the high elevations, separated completely and frequently isolated from one another in this manner by great distances.

The staple foodstuffs of India grow on the plains, the hills growing only special crops such as temperate fruits and vegetables, with a mere smattering of the staple crops such as wheat, *jowar*, maize, pulses etc. The staple foodstuffs (the pulses and cereals) and also the major fruits (oranges, mangoes bananas etc.) are grown throughout the lower elevations of India. Naturally there are areas particularly noted for certain crops. Thus, for example, the drier belt of the northern plains (west United Provinces and the Punjab) relies largely on gram (*Cicer arietinum* L.) as a pulse, whereas the wetter part of the plains (east United Provinces and Bihar) grows mainly pigeon-pea (*Cajanus cajan*). Yet both gram and pigeon-pea can be found in considerable quantities in Bihar and the Punjab—and indeed in any province of India. Rice, the staple diet of large parts of Bengal, Madras, and Kashmir, is a crop eminently suited for wet climates, yet it will be found in small quantities even in very dry areas provided a small spot of low-lying land can be found near a river-bed. Similarly the best bananas, and by far the largest quantities, are grown in Southern India (Madras, Bombay, Mysore etc.) but there are no low-land parts of India without their bananas, usually their own local variety.

With commercial crops, there is some difference. Jute, for instance, is restricted to a small area in Bengal, coffee to Travancore and Mysore, and tea to a few districts in Southern India and the north-eastern Himalayas. On the other hand sugarcane, which has developed commercially only in Bihar and the United Provinces to a substantial extent, is grown all over India for local consumption.

The crops of India may conveniently be divided into six categories, as follows :—

(1) The staple foodstuffs (grains and pulses) grown throughout the northern plains and southern lowlands, and to a very small extent in the hills.

(2) The sub-tropical and tropical fruits, with a similar distribution.

(3) Commercial crops of restricted distribution (e.g. jute, tea and coffee) limited by climatic factors.

(4) Commercial crops of wide distribution (e.g. cotton, tobacco and sugarcane).

(5) Temperate crops of restricted distribution (e.g. temperate fruits such as apples, pears and plums) grown in the hills.

(6) Temperate crops of wide distribution (e.g. common European vegetables) grown during the warm weather in the hills and during the cold weather on the plains.

Distribution of diseases

No systematic survey of diseases has ever been conducted in India, for the simple reason that the number of plant pathologists has never been adequate. We are, however, able to get a certain amount of information in some cases, and since the question of quarantine cannot even be intelligently considered without some knowledge of disease distribution we have drawn heavily on published literature to gain some insight of the subject. Numerous publications have been referred to, but particular mention may be made of '*Fungi of India*' by Butler and Bisby, the '*Fungi of India—Supplement I*' by Mundkur, and '*Fungi of Bombay*' by Uppal, Patel and Kamat. By reference to these and numerous other publications it has been possible to list in Table I, we hope without many omissions, the recorded occurrence of the important diseases of a number of selected crops. In preparing this table we have selected a few important crops from all six 'categories' described above. We have listed all the diseases occurring on these crops in India which have either shown themselves capable of causing severe damage in India itself or else are known to cause severe injury in some other country. The diseases thus analysed total sixty-eight.

Table I

Recorded distribution of fungous diseases of some important Indian crops, which cause severe damage or are considered potentially dangerous judging by their behaviour elsewhere

Crop	Category	Disease	Cause	Distribution
Wheat	1	Stem rust	*Puccinia graminis* Pers.	General
		Brown rust	*Puccinia triticina* Erikss.	General
		Yellow rust	*Puccinia glumarum* (Schm.) Erikss. and Henn.	Northern India and Nilgiris
		Loose smut	*Ustilago tritici* (Pers.) Jensen.	General
		Leaf spot	*Septoria tritici* Desm.	Punjab
		Root-rot	*Helminthosporium sativum* P. K. and B.	Pusa (Bihar)
		Flag smut	*Urocystis tritici* Koern.	Punjab
		Indian bunt	*Neovossia indica* (Mitra) Mundkur	Punjab and N.-W. F. P.
		Bunt	*Tilletia caries* (DC.) Tul. *Tilletia foetans* (Berk. and Curt.) Tul.	Himalayas
Barley	1	Covered smut	*Ustilago hordei* (Pers.) Kellerm. and Swingle	General
		Stem rust	*Puccinia graminis* Pers.	General
		Yellow rust	*Puccinia glumarum* (Schm.) Erikss. and Henn.	Northern India and Nilgiris

TABLE I—*contd.*

Crop	Category	Disease	Cause	Distribution
Barley	1	Stripe	*Helminthosporium gramineum* Rabenh.	Pusa (Bihar) and Punjab
		Root-rot	*Helminthosporium sativum* P. K. and B.	Pusa (Bihar) and Punjab
		Net blotch	*Helminthosporium teres* Sacc.	Pusa (Bihar) and Punjab
Oats	1	Smut	*Ustilago avenae* (Pers.) Jensen	General
		Leaf spot	*Helminthosporium avenae* Eid.	General
Jowar (Sorghum)	1	Grain smut	*Sphacelotheca sorghi* (Link) Clinton	General
		Long smut	*Tolyposporium Ehrenbergii* (Kühn) Pat.	General
		Downy mildew	*Sclerospora sorghi* (Kulk.) West. and Uppal	General
Pigeon-pea	1	Wilt	*Fusarium vasinfectum* Atk. (?)	General
		Root-rot	*Macrophomina phaseoli* (Maubl.) Ashby	General
Gram	1	Blight	*Mycosphaerella rabiei* Kovachevsky	Punjab and N.-W. F. P.
		Wilt	*Fusarium* sp.	General
Citrus	2	Canker	*Pseudomonas citri* Hasse	General
		Gumosis	*Phytophthora palmivora* Butler	Throughout the Bombay-Deccan.
		Wither-tip	*Colletotrichum gloeosporioides* Penz.	General
Mango	2	Sooty mould	*Dimerosporium mangiferum* Cke. and Br.	Mysore ; Punjab and U. P.
		Twig blight	? *Dothiorella mangiferae* Syd.	Lucknow, U. P.
		Anthracnose	*Glomerella cingulata* (Stonem.) Spauld. and v. Schrenk	Madras and Punjab (common on other hosts elsewhere)
Jute	3	Root-rot	*Macrophomina phaseoli* (Maubl.) Ashby	Bengal (and throughout India on other hosts)
Rubber (*Hevea*)	3	Leaf-fall	*Phytophthora palmivora* Butler	Throughout the *Hevea*-growing districts of Burma and South India
			Phytophthora meadii McRae	There is some confusion as to the identity of the two organisms, Dastur having suggested that they are identical. In any case *Phytophthora palmivora* at least is widespread on several hosts
		Pink disease	*Corticium salmonicolor* B. and Br.	Widespread in the *Hevea*-growing districts of Assam, Burma and South India
		Mildew	*Oidium heveae* Steinman	Travancore
		Leaf-fall	*Gloeosporium alborubrum* Petch.	Travancore
		Die-back	*Botryodiplodia theobromae* Pat.	Burma. The fungus is of general distribution on other hosts
		Root-rot	*Fomes lamoensis* (Murr.) Sacc. and Trott.	*F. lamoensis* is of general distribution ; *G. pseudoferreum* has been reported from Burma
			Ganoderma pseudoferreum (Wakef.) von Overeem and Steinman (*Fomes pseudoferreus* Wakef.)	

TABLE I—*concld.*

Crop	Category	Disease	Cause	Distribution
Sugarcane	4	Red-rot	*Colletotrichum falcatum* (Went.)	General
		Wilt	*Cephalosporium sacchari* Butler	General
		Smut	*Ustilago scitaminea* Syd.	General
		Top-rot (Pokkah-beong)	*Fusarium moniliforme* Sheld.	General
		Mosaic	Virus	General
Cotton	4	Wilt	*Fusarium vasinfectum* Atk.	General
		Root-rot	*Macrophomina phaseoli* (Maubl.) Ashby	General
		Anthracnose	*Glomerella Gossypii* (Southw.) Edg.	Pusa (Bihar)
		Blight	*Colletotrichum indicum* Dastur	Central Provinces
		Angular leaf-spot	*Pseudomonas malvacearum*.	Punjab
Tobacco	4	Leaf-spot	*Cercospora nicotianae* Ell. and Ev.	General
		Wilt	*Bacterium solanacearum* E. F. Sm.	Bengal (and in various parts of India on potatoes)
		Mildew	*Erysiphe cichoracearum* DC.	General
	4	Mosaic	Virus	General
		Leaf-curl	Virus	Northern India and Bombay
Coconut	4	Bud-rot	*Phytophthora palmivora* Butler	Throughout the coconut districts of Bengal, Madras and Southern India. The disease is also common on *Borassus flabellifer* almost wherever grown
		Root-rot	?	Widespread in the Southern Peninsula
		Bleeding disease	*Thielaviopsis paradoxa* (de Seynes) v. Hohnel	Throughout southern and eastern India
Peach	5	Powdery mildew	*Sphaerotheca pannosa* (Wollr.) Lev.	Kashmir
		Leaf-curl	*Taphrina deformans* (Berk.) Tul	Mountainous tracts of Assam, Bihar, U. P., Kashmir, Punjab and N.-W. F. P.
		Brown-rot	*Sclerotinia cinerea* (Bon.) Schroet.	Kashmir ?
Apples	5	Root-rot	? *Rosellinia* sp.	United Provinces
		Die-back	*Botryosphaeria ribis* G. and D.	United Provinces
		Branch blister	*Coniothecium chomatosporum* Cda.	Kumaon hills, U. P.
		Powdery mildew	*Podosphaera leucotricha* (Ell. and Ev.) Salmon	Punjab, Kashmir and United Provinces
		Scab	*Venturia inaequalis* (Cooke) Wint.	Kashmir and Punjab
Potatoes	6	Early blight	*Alternaria solani* (Ell. and Mont.) Jones and Grout	General
		Scab	*Actinomyces scabies* (Thaxt.) Gussow	Khasi hills and Bombay
		Late blight	*Phytophthora infestans* de By.	Himalayas, Khasi hills, Assam, Bengal plains
		Dry-rot	*Fusarium* spp.	General
		Bacterial wilt	*Bacterium solanacearum* E. F. Sm.	Bombay, Mysore, United Provinces, Nilgiris

The following conclusions can be drawn from the table (Table I) at a glance.

(1) Of the sixty-eight diseases considered, twenty-seven are of general distribution throughout India, while in another six cases the fungi concerned have a wide distribution on other hosts. Of the remaining thirty-one diseases, fourteen are common in most parts of the country where the crops are grown, but have not been listed as being of 'general ' distribution because the crop itself is rather limited to special areas.

(2) There remain only twenty-one diseases of which the records indicate possibly a narrower distribution.

(3) The proportions of cases in which possibly a narrow distribution is indicated, as divided amongst the various crop categories, are indicated in Table II.

TABLE II

Proportions of diseases of wide and narrow distributions in India

Category	Description	Diseases of fairly wide distribution	Diseases of possibly narrower distribution
1	Staple foodstuffs (grains and pulses)	16	8
2	Sub-tropical and tropical fruits	5	1
3	Commercial crops of restricted distribution	5	2
4	Commercial crops of wide distribution	15	3
5	Temperate crops of restricted distribution	2	6
6	Temperate crops of wide distribution	4	1

In reaching the above conclusions, however, one point must be made clear. If the figures err at all, they err in the direction of multiplying unduly the ' diseases of possibly narrower distribution '. Three of these diseases (root-rot of barley, scab of potatoes, root-rot of apples) are soil-borne and may readily have escaped identification. Some are no doubt restricted by climatic conditions to certain districts. Yet others may have been observed in other districts but not reported, or may have escaped observation.

FEASIBILITY AND LIMITATIONS OF QUARANTINE BETWEEN NEIGHBOURING PROVINCES

It has been pointed out that geographically India consists of one large plain with a number of isolated hill or mountain tracts. The provincial boundaries bear very little relationship to the topography, and the hill tracts may be divided between a number of provinces. The natural barriers in the form of

mountains or deserts or climatic conditions are few. A large number of severe diseases are widespread ; a few may be of more limited distribution. Several questions now arise. Can we expect to control the spread of diseases by inter-provincial regulation of traffic in plants and plant products ; if so, should legislation be general or restricted to certain diseases ; and finally is it likely to pay, the anticipated savings being likely to exceed the cost of administration ?

There is at present a considerable inter-provincial trade in propagative material and material such as grains and pulses capable of being used for propagative purposes. The propagative materials include seeds, tubers, cuttings, seedlings, bulbs etc. The food-stuffs liable to transport diseases are mainly seeds, fruits and tubers. There is no guarantee that goods transported for consumption will not be used for propagation.

There are large numbers of points of entry between one province and another, and transport may be by road, rail or water.

There are, according to McCubbin [1936] five recognized types of quarantine action :—

Embargo
Detention
Disinfection
Inspection
Unrestricted entry

Embargo could certainly only be applied in very rare cases. It probably could not be used for crops of categories 1 and 2 (basic foodstuffs and fruits of the plains) in which there is extensive inter-provincial trade. The indications are that in crops of categories 3 and 4 (commercial crops) the potentially dangerous diseases are widely distributed and quarantine measures are not called for.

Detention, which means holding in quarantine during a fixed period of observation, needs a far greater expert staff than embargo. It might be adopted in the case of a few specific crops of categories 3 (commercial crops of restricted distribution) and 5 (temperate crops of restricted distribution), provided a specific case was made out.

The value of disinfection has been analysed by McCubbin and has been shown to be an important procedure only in the case of seeds. At the present time, however, we have no means of knowing, for the vast bulk of seeds transported (cereals and pulses) whether they are to be used for seed or consumption. Many of the best disinfectants are poisonous and there is little doubt that disinfected seed crossing a provincial frontier would lead to numerous cases of litigation and finally to a serious hampering of trade, to say nothing of the immense staff required for the purpose of disinfecting.

Inspection has been shown by McCubbin to have in itself very low rank for purposes of exclusion ; at the same time it requires a very large expert staff. It is considered by McCubbin to be a distinct quarantine function only when it alone is depended on as a means of protection. There are certain cases of vegetatively propagated plants, such as fruit trees and grafts, in which a considerable trade is done. Embargo is out of the question and disinfection methods cannot be used unless the exact details of the disinfection required

are known. If we are to have protection it must be through inspection or detention, and since detention may in some cases result in severe damage to the plants, inspection may prove most useful.

Unrestricted entry is considered by McCubbin to be safe for a large proportion of seeds. This is particularly fortunate, for the inter-provincial commerce in seeds, used either for propagation or for food, must be very great and there is little hope of adopting, at the present time at any rate, any method of treating this type of product, or even of adequately inspecting it.

To summarize, it seems that for the bulk of plant products in India, i.e. the foodstuffs (grains, pulses and fruits) grown on the plains, we are not at present justified in establishing inter-provincial quarantines, for the following reasons :–

(1) Embargoes would interfere with trade, detention is useful only for growing plants, and disinfection is dangerous.

(2) Adequate inspection of plant products generally would involve staffs completely beyond the power of the provinces to provide.

(3) The plains crops are on the whole widely distributed. Many of their diseases are similarly distributed, but in the absence of survey data we cannot say if this is true for all. It is difficult to name more than one or two cases where inter-provincial quarantine of this type could be expected to pay for itself.

(4) In these crops the largest commerce is in seeds, which according to McCubbin are the most safe category of plant products for unrestricted entry ; and fruit, which possibly does not serve largely as a distributor of disease.

(5) The plains crops are widely distributed, with few natural boundaries to prevent spread of diseases.

It is possible, however, that even amongst these crops there are specific cases for quarantine in propagating materials other than seed. In bananas the dangerous virus disease ' bunchy top ' has recently been suspected in two places in India. There is every reason why measures should be adopted to prevent suckers being sent from these places to healthy districts. Other similar cases may exist amongst virus diseases of vegetatively propagated plants.

The commercial crops of wide distribution such as sugarcane and tobacco have a very high proportion of their diseases distributed over wide areas, indicating that here little would be gained by quarantine measures. Those of narrower distribution have not been sufficiently thoroughly analysed to reach a very reliable decision, but even here the indications are of fairly wide distribution except in the case of two newly reported rubber diseases. Some restrictions designed to prevent distribution of rubber mildew (*Oidium hevae* Steinman) seem called for and should not be impossible with a crop grown by large planters.

As regards temperate crops, very considerable sums are at present being spent in research on cultivation of fruit in the hills. Many of the zones are well isolated from one another by long stretches of unfavourable climate. It seems as if there might be cases here for adopting the practice of examination and detention when plant parts for propagation are sent from one area to another. There would, however, be certain inter-provincial boundaries where the rules might be relaxed, as these boundaries do not as a rule coincide with topographical areas.

Basis for legislative action

The National Plant Board of America [1932] has indicated four fundamental prerequisites for the establishment of a quarantine, which do not suffer from repetition. They are as follows :—

(1) The pest concerned must be of such nature as to offer actual or suspected threat to substantial interests ;

(2) the proposed quarantine must represent a necessary or desirable measure for which no other substitute, involving less interference with normal activities, is available ;

(3) the objective of the quarantine, either for preventing introduction or for limiting spread, must be reasonable of expectation ;

(4) the economic gains expected must outweigh the cost of administration and the interference with normal activities.

The first prerequisite has a striking significance which may easily be overlooked. It eliminates at once the idea of basing legislation on a general footing. Experience has shown that the proper basis is the individual pest or disease. The obvious sequence is that we must know the distribution of our pest, or pathogen, its life-history, its potentiality for damage and the definite possibility of gains resulting from quarantine action. We now have a fair knowledge of many life-histories, and have a fair idea of potentialities for damage. We lack in many cases the all-important knowledge of distribution. The most likely place where quarantine may successfully and profitably be established seems to be in isolated hill tracts where efforts are being made to establish new temperate fruit and vegetable crops or to extend their cultivation. It is exactly in these crops that our knowledge of distribution is most lacking. The case of *Botryosphaeria ribis* causing the die-back disease, and *Venturia* causing scab of apples are cases where quarantine legislation might be valuable. There may be others also.

Intensive survey work is being done in Chaubattia (U. P.) and it needs extension to other areas. This is our fundamental requirement in India, and until this is fulfilled we do not seem to be in a position to meet the ' fundamental prerequisites ' outlined by the Plant Board of the United States of America.

Summary

The crops of India may conveniently be divided for quarantine considerations into six categories, as follows :—

(1) The staple foodstuffs (grains and pulses) grown throughout the northern plains and southern lowlands, and to a very small extent in the hills.

(2) The sub-tropical and tropical fruits, with a similar distribution.

(3) Commercial crops of restricted distribution (e.g. jute, tea and coffee) limited by climatic factors.

(4) Commercial crops of wide distribution (e.g. cotton, tobacco and sugarcane).

(5) Temperate crops of restricted distribution (e.g. temperate fruits such as apples, pears and plums) grown in the hills.

(6) Temperate crops of wide distribution (e.g. common European vegetables) grown during the warm weather in the hills and during the cold weather on the plains.

In the absence of any systematic survey data for India, an analysis has been made from various published works which gives the best possible indication of the occurrence in India of sixty-eight diseases of important crops. These diseases are only those which are known to cause severe damage where they occur in India or in other countries. It is found that in thirty-three cases the organisms concerned are widespread throughout India, while at least fourteen more are found almost throughout the narrow geographical limits of the crop concerned. There remain only twenty-one cases in which the records indicate a possibly narrower distribution, though for reasons stated this figure is probably an over-estimation.

In considering the applicaton of quarantine measures the problem has been considered from various aspects. The principles recognised by the National Plant Board of the United States of America have been taken into consideration. These are briefly as follows :—

(1) The pest concerned must offer a threat to substantial interests.
(2) There must be no better substitute for the proposed quarantine.
(3) The objective of the quarantine must be reasonable of expectation.
(4) The economic gains must outweigh the cost of administration.

Adopting these principles, the various crop categories have been considered individually from the point of view of the five types of quarantine action recognised by McCubbin, namely, embargo, detention, disinfection, inspection, and unrestricted entry.

The conclusion reached is that the only strong case for inter-provincial quarantine in India is in the temperate crops of restricted distribution (the temperate fruits of the hills). There may perhaps be one or two special cases in virus diseases of vegetatively propagated crops on the plains, but national regulations are dependent on survey work for which at the present time India has no facilities.

REFERENCES

McCubbin, W. A. (1936). *Phytopath.* **26**, 991-1006

National Plant Board of America (1932). *Phytopath.* **22**, 933-5

THE GENUS *FUSARIUM*

IV. INFECTION AND CROSS-INFECTION TESTS WITH ISOLATES FROM COTTON (*GOSSYPIUM* SP.), PIGEON-PEA (*CAJANUS CAJAN*) AND SUNN-HEMP (*CROTALARIA JUNCEA*)

BY

G. WATTS PADWICK

Imperial Mycologist

M. MITRA

Assistant Mycologist

AND

P. R. MEHTA

Formerly Assistant to Imperial Mycologist, Imperial Agricultural Research Institute, New Delhi

(Received for publication on 5 February 1940)

(With Plates XXVIII and XXIX)

INTRODUCTION

IN the first paper of this series [Padwick, 1939] it was pointed out that contradictory evidence exists with regard to the ability of the species of *Fusarium* isolated from cotton (*Gossypium* sp.), pigeon-pea (*Cajanus cajan*) and sunn-hemp (*Crotalaria juncea*) to pass from one host to another and bring about infection.

Butler [1918] said ' The pigeon-pea *Fusarium* has not been found on any other plant '. When Vincens [1921] described the wilt disease of *Crotalaria* he said that the organism more closely resembled *F. udum* Butl. than *F. vasinfectum*. Small [1920] made isolations from wilted carnations, *Nigella* and *Delphinium* and found that the fungi isolated could readily cross-infect the three host species. Again the same author [Small, 1922] referred to successful cross-inoculation of *Delphinium* with an organism from cashew (*Anacardium occidentale*). A similar fungus was isolated from *Grevillia robusta* and caused infection of *Grevillia* plants but not of *Eugenia jambos* and *Eriobotrya japonica*, from which isolates of similar appearance were obtained. Pigeon-peas grown in soil known to be infected succumbed to wilt and the *Fusarium* was isolated. It was considered to be *F. udum* Butl. In a later paper Small [1925] related that a *Fusarium* considered to be *F. udum* was found associated with potato-tuber rotting. It was proved to be able to rot potatoes and sweet potatoes. The fungus was also found on wilted beans (*Phaseolus* sp.) but could not reproduce the disease under normal conditions, though it could cause disease under conditions exceptionally favourable for its development. The conclusion was reached that the pathogenicity of *F. udum* ' depends less on the strain of the fungus and the presence of a possible host plant than on the environmental conditions under which the fungus comes into contact with its host '. Hansford [1939] concludes that the

Fusaria associated with wilt diseases of some plants in Uganda are not restricted in pathogenicity to a single species of host.

Mitra [1934] found that *Fusarium vasinfectum* attacking sunn-hemp can attack also pigeon-pea, though not cotton, whereas Uppal and Kulkarni [1937] were unable to infect sunn-hemp with the organism from pigeon-pea or *vice versa*.

It was with a view to throwing light on this controversy that isolations and cross-inoculation studies were made. These are described in this paper.

Material

For the purposes of this study infected material was obtained from wilted cotton seedlings from Parbhani (Hyderabad, Deccan); from wilted pigeon-pea from Pusa (Bihar), Rudroor (Hyderabad, Deccan) and Cawnpore (U. P.); from wilted sunn-hemp from Pusa (Bihar) and Cawnpore (U. P.). Cultures of *Fusarium vasinfectum* from cotton and from sunn-hemp were kindly supplied by Dr B. N. Uppal, Plant Pathologist to the Government of Bombay.

Experimental

The isolations were made during a period of sixteen months, and it was only towards the end of this period that a standardised method of isolating and recording the results was adopted. Thus for a few of the isolates studied data are incomplete as to the number of pieces of tissue plated out and the number of similar isolates obtained. Some of the earlier isolates were made from comparatively superficial tissue of the wilted plants, whereas at the later dates not only the bark but a deep layer of the cortex was removed and only the innermost woody tissues were taken for plating. In the earlier isolates the method of isolation was immersion of the tissue in 0·1 per cent mercuric chloride solution for two minutes followed by washing in alcohol, whereas later the pieces were immersed for two minutes in one per cent silver nitrate solution and then dipped in two per cent sodium chloride solution in order to deposit the silver as chloride.

Three experiments in all were conducted. The first and second were done in 1938, and were merely preliminary tests of pathogenicity of the early pigeon-pea isolates on pigeon-pea and sunn-hemp isolates on sunn-hemp respectively. The third experiment was made in 1939. By this time fifty-one representative isolates had been selected for the study and all these isolates were tested for infectivity of cotton, pigeon-pea and sunn-hemp. The method used in this experiment will here be described in detail and apart from minor points the same method was used for the first two experiments.

Single-spore cultures of certain of the isolates were obtained by marking the single spores in dilution plates and removing them when they had germinated. The cultures were grown on a sterilized mixture of ten parts cornmeal, ninety parts soil and thirty parts water in Erlenmeyer flasks. The soil was inoculated on June 26th and 27th, 1939, and the fungus allowed to grow until July 19th, when the soil was removed from the flasks, after making brief notes on the amount of growth of each isolate. This growth was recorded as follows :—

Poor (very little penetration of soil).

Moderate (mycelium apparently grown about half-way through the soil).

Good (most of the soil ramified by mycelium).

Excellent (soil completely ramified by mycelium).

The soil in all the flasks of one isolate was thoroughly mixed.

Soil sufficient for 620 eleven-inch earthenware flower-pots, prepared by mixing one load of well-rotted cowdung with five loads of silty Delhi soil was sterilized in autoclaves at 20 lb. per square inch pressure on July 17th to 20th. After thorough mixing it was placed in the pots.

In each pot 150 gm. of inoculum were spread on the surface of the soil, except with cultures F 25, F 152 and F 6, of which the quantities were respectively 125, 130 and 125 gm. only, due to rejection of certain contaminated flasks. In this way twelve pots were infested with each organism, sufficient for four pots each of cotton, sunn-hemp and pigeon-pea. In addition there were, as controls, forty-eight pots (sixteen for each host) of similarly sterilized soil to each of which was added 150 gm. of sterilized maize-meal-soil mixture without any organism. Eight seeds of cotton (Malvi 9, kindly supplied by the Botanist, Institute of Plant Industry, Indore), pigeon-pea (I. P. Type 5) and sunn-hemp (a local variety from Pusa) were placed in their respective pots (four replicates of each culture and sixteen controls) and were covered with sterilized soil. All the host varieties used are known to be highly susceptible to wilt.

The first wilted cotton plant appeared on August 16th, twenty-seven days after sowing. The first appearance of wilt in pigeon-pea was on August 2nd when the seedlings were only thirteen days old, and in sunn-hemp on August 7th when the seedlings were eighteen days old. For several weeks the development of wilt was slow, but gradually increased until on September 11th the maximum was reached with fifty-one plants wilting on that day. After September 20th wilting fell off rapidly so that in the first week of October only thirty-four plants wilted. Owing to the large size of the plants at this time they showed signs of crowding in the pots and the experiment was discontinued on October 10th. Each day as the wilted plants were observed they were kept and numbered for the purpose of isolation.

The methods used in the first two experiments differed from those in the third mainly as regards the following :—

(1) Only six-inch pots were used, with six seeds in each, but there were six replicates.

(2) Prior to sowing the seeds were sterilized with formalin. After some deliberation this was not done in the third experiment owing to the possible danger of interfering with germination.

The results of these experiments are summarized in Table I. The host and locality are listed, together with the number of morphologically similar isolates and the total number of isolates of *Fusarium*. It is also stated whether the cultures were obtained from single spores. In columns 8-13 will be found the total number of seedlings which germinated and the number of plants which wilted in the third experiment, while in parenthesis the results of the first and second experiments are given. The amount of growth noted in the flasks is also given in Table I.

TABLE I

Pathogenicity of isolates of Fusarium *from pigeon-pea, cotton and sunn-hemp in cross-inoculation tests*

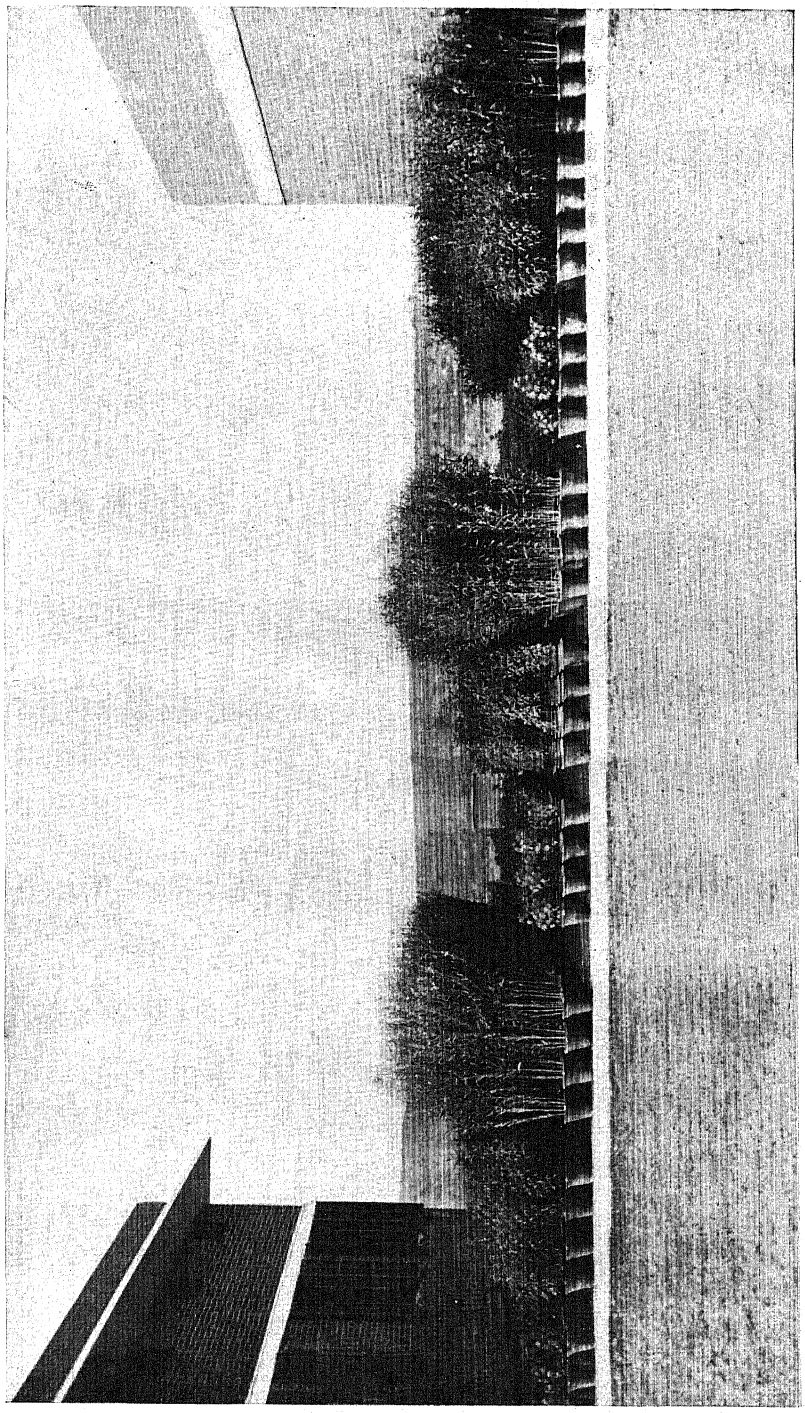
Culture	Host	Locality	Single-spore (SS) or mass (M) culture	Number of similar isolates	Total number of *Fusarium* isolates	Condition of growth in flasks	Pathogenicity*					
							Cotton		Pigeon-pea		Sunn-hemp	
							Seeds germinated	Plants wilted	Seeds germinated	Plants wilted	Seeds germinated	Plants wilted
F 25	Cotton	Bombay : Supplied by Dr B. N. Uppal	...	...	...	Poor .	19	4	32 (36)	1 (0)	31	0
F 88	,,	Parbhani, Hyderabad (Deccan)	M	21	21	Excellent	15	1†	32	0	29	1†
F 96	,,	,,	M	...	...	,,	23	1†	22	0	29	0
F 97	,,	,,	M	...	...	Moderate	18	0	31	0	31	0
F 140	,,	,,	M	1	1	Excellent	5	0	1	0	30	0
F 141	,,	,,	M	1	1	Moderate	3	0	32	0	23	0
F 142	,,	,,	M	2	3	,,	12	1†	32	0	10	0
F 143	,,	,,	M	1	3	Good	11	0	31	0	32	0
F 144	,,	,,	M	1	3	Moderate	11	0	31	0	26	0
F 145	,,	,,	M	1	3	,,	22	2†	32	1	32	0
F 147	,,	,,	M	5	5	Poor	23	18	31	0	30	0
F 148	,,	,,	M	1	1	Excellent	17	0	8	2†	31	0
F 149	,,	,,	M	1	3	,,	17	0	5	0	32	0
F 150	,,	,,	M	2	3	,,	8	0	10	0	30	0
F 152	,,	,,	M	1	2	Good	26	0	31	0	31	0
F 153	,,	,,	M	1	2	Moderate	0	0	17	0	2	0
F 154	,,	,,	M	2	2	,,	20	0	32	1	31	0
F 1	Pigeon-pea	Pusa, Bihar	SS	...	...	,,	15	0	13 (35)	0 (0)	31	0
F 2	,,	,,	SS	...	...	Poor	20	0	32 (33)	26 (17)	32	0

F 3	,,	,,	SS	...	...	Moderate	18	0	31 (26)	3 (0)	30	0
F 4	,,	,,	SS	...	...	,,	21	0	32 (17)	0 (7)	29	1
F 5	,,	,,	M	3	16	Poor	26	0	32 (36)	25 (32)	28	0
F 6	,,	,,	M	7	16	,,	25	0	32 (35)	31 (32)	29	0
F 7	,,	,,	M	1	16	,,	24	0	32 (35)	30 (27)	30	0
F 8	,,	,,	M	8	16	...	...	...	— (15)	— (0)	...	...
F 9	,,	,,	M	1	16	Moderate	19	0	31 (8)	1 (0)	31	0
F 10	,,	,,	M	2	16	Poor	24	0	32 (33)	32 (25)	30	1
F 11	,,	,,	SS	5	5	,,	22	0	31 (34)	26 (32)	30	5 (In one replicate only)
F 12	,,	,,	SS	4	6	,,	19	0	32 (32)	27 (31)	30	2
F 59	,,	Rudroor, Hyderabad (Deccan)	M	6	6	,,	24	0	32	10	30	0
F 137	,,	Pusa, Bihar	SS	10	10	Moderate	21	0	32	32	32	3
F 138	,,	,,	SS	7	8	Excellent	23	0	32	0	31	0
F 139]	,,	,,	SS	1	8	Poor	23	0	32	29	29	0
F 164	,,	Cawnpore, U. P.	SS	10	10	Moderate	23	0	32	30	31	2
F 165	,,	,,	SS	10	10	,,	21	0	32	26	30	2
F 171	,,	Pusa, Bihar	SS	10	10	,,	28	0	32	31	31	0
F 172	,,	,,	M	10	10	Poor	21	0	32	32	32	0
F 173	,,	,,	SS	9	9	,,	26	0	32	32	32	0
F 174	,,	,,	SS	10	10	,,	21	0	31	26	30	0
F 175	,,	,,	SS	10	10	,,	24	0	32	24	30	2
F 176	,,	,,	SS	10	10	,,	19	0	32	30	31	1
F 13	Sunn-hemp	,,	M	1	21	,,	20	1†	31	31	32 (36)	1 (0)
F 14	,,	,,	M	9	21	Moderate	19	0	31	1	31 (31)	0 (0)
F 15	,,	,,	M	2	21	,,	20	0	32	30	32 (36)	1 (0)
F 17	,,	,,	M	3	21	...	...	...	...	...	— (29)	— (13)

* Figures in parenthesis refer to experiments 1 and 2.
† Symptoms not quite typical of *Fusarium* wilt.

TABLE 1—*concld.*

Culture	Host	Locality	Single-spore (SS) or mass (M) culture	Number of similar isolates	Total number of *Fusarium* isolates	Condition of growth in flasks	Pathogenicity					
							Cotton		Pigeon-pea		Sunn-hemp	
							Seeds germinated	Plants wilted	Seeds germinated	Plants wilted	Seeds germinated	Plants wilted
F 18	Sunn-hemp	Pusa, Bihar	M	4	21	Poor	23	0	32	2	32 (35)	10 (11)
F 19	,,	,,	SS	3	3	Good	20	0	32	0	27 (31)	6 (18)
F 26	,,	Bombay : Supplied by Dr B. N. Uppal	...	...	...	Poor	20	0	32 (36)	0 (0)	32 (32)	14 (12)
F 166	,,	Cawnpore, U. P.	SS	10	10	Moderate	20	0	32	0	30	23
F 167	,,	,,	SS	1	1	Excellent	23	0	32	0	31	7
F 168	,,	Pusa, Bihar	SS	10	10	Moderate	24	0	32	0	30	23
F 169	,,	,,	SS	1	2	Excellent	24	0	32	0	31	9
F 170	,,	,,	M	1	2	,,	17	0	11	0	30	5
Control	...	...	...	...	...	...	71	1	126 (77)	2 (0)	118 (41)	4 (0)



General view of cross-inoculation experiment with isolates of *Fusarium* from cotton, pigeon-pea and sunn-hemp

The effects of several isolates of *Fusarium* on germination of cotton, pigeon-pea and sunn-hemp seeds



FIG. 1. *Fusarium* No. 140

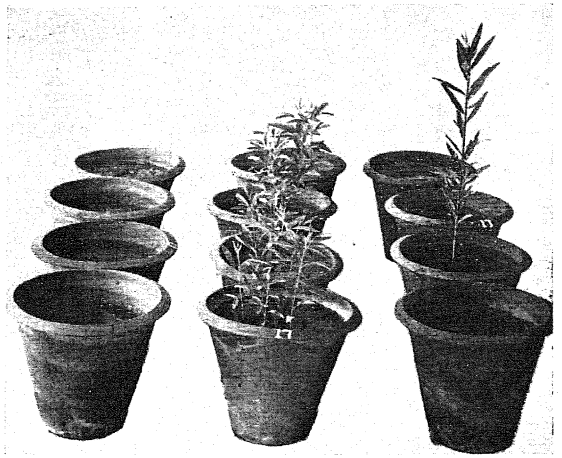


FIG. 3. *Fusarium* No. 153

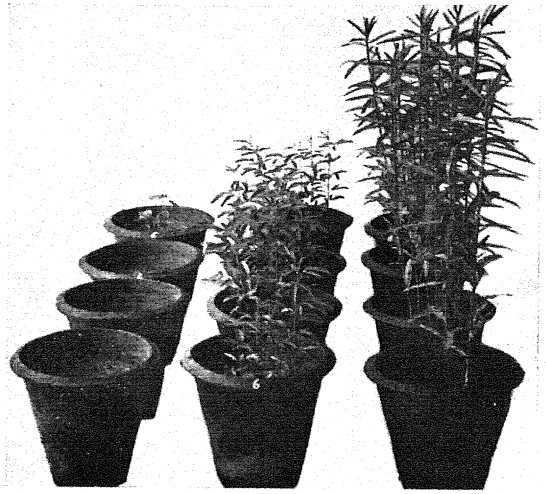


FIG. 2. *Fusarium* No. 141



FIG. 4. Control

Plate XXVIII illustrates the general lay-out of the main experiment, and Plate XXIX shows a closer view of some of the series in infested soil, illustrating clearly the inhibition of germination.

TABLE II

Summary of infection levels in the wilt-producing organisms

Culture	Isolated from	Cotton plants wilted	Pigeon-pea* plants wilted	Sunn-hemp* plants wilted	Growth of fungus in flasks of soil
F 147	Cotton	18	0 (17)	0	Poor
F 2	Pigeon-pea	0	27 (17)	0	,,
F 5	,,	0	25 (32)	0	,,
F 6	,,	0	31 (32)	0	,,
F 7	,,	0	30 (27)	0	,,
F 10	,,	0	32 (25)	1	,,
F 11	,,	0	26 (32)	5 (In one replicate only)	,,
F 12	,,	0	27 (31)	2	,,
F 59	,,	0	10	0	,,
F 137	,,	0	32	3	Moderate
F 139	,,	0	29	0	Poor
F 164	,,	0	30	2	Moderate
F 165	,,	0	26	2	,,
F 171	,,	0	31	0	,,
F 172	,,	0	32	0	Poor
F 173	,,	0	32	0	,,
F 174	,,	0	26	0	,,
F 175	,,	0	24	2	,,
F 176	,,	0	30	1	,,
F 13	Sunn-hemp	1	31	1 (0)	,,
F 15	,,	0	30	1 (0)	Moderate
F 17	,,	..	..	13	
F 18	,,	0	2	10 (11)	Poor
F 19	,,	0	0	6 (18)	Good
F 26	,,	0	0 (0)	14 (12)	Poor
F 166	,,	0	0	23	Moderate
F 168	,,	0	0	23	,,
		Doubtful cases			
F 25	Cotton	4	1 (0)	0	Poor
F 3	Pigeon-pea	0	3 (0)	0	Excellent
F 4	,,	0	0 (7)	1	Moderate
F 167	Sunn-hemp	0	0	7	Excellent
F 169	,,	0	0	9	,,
F 170	,,	0	0	5	,,

* Figures in parenthesis refer to experiments 1 and 2.

Conclusion

The major experiment, on which our conclusions must largely be based, involved the use of fifty-one cultures, some hundreds of flasks, and over 600 pots containing in all about four tons of soil which had to be sterilized. Once completed there were numerous ways in which contamination from pot to pot could take place—by water, animals, birds and insects, and workers' hands to mention only a few. Precautions were taken to reduce these to a minimum. Taking into account these various possible sources of error the number of wilted plants appearing in the controls can be considered very low.

Considering the results first in a quite general way, we find that of the sixteen isolates from cotton seedlings from Hyderabad, only one caused wilt but a number of them prevented normal germination. It is noteworthy that the various isolates showed different tendencies in this respect. For example F 140 practically inhibited germination of cotton and pigeon-pea ; F 142 severely reduced germination of cotton and sunn-hemp but had no deleterious effect on pigeon-pea ; while F 153 reduced the germination of all three. None of the isolates which produced this harmful effect on germination appeared capable of causing wilt at a later stage.

Owing to a certain number of wilted plants appearing in the controls it is necessary to take a safe margin of percentage infection as an indisputable proof of pathogenicity. It is therefore proposed to accept ten or more wilted plants as a reliable indication of ability of the fungus to produce wilt. Less than ten wilted plants may be regarded with a certain amount of reservation, while cases with two plants or less may be disregarded entirely. Adopting this procedure we are able to list the cases of proved pathogenicity and the doubtful cases, together with the number of plants wilted and the condition of growth of the fungi in the flasks of soil. We thus get in Table II a brief summary of the salient points of Table I.

It is very clear that the most pathogenic isolates are almost, if not entirely, restricted to one host. Curiously enough, it happens that two isolates, F 13 and F 15, obtained from sunn-hemp, produced only a wilt of pigeon-pea. These two isolates were obtained from the same group of plants as F 17 and F 18, both of which produce only wilt of pigeon-pea. These particular isolations were made before the technique had been perfected and it is quite possible that they may have come from the superficial cortical tissue. One can easily see how, with a mass culture, one might obtain both strains from such tissue as a mixture. Both the pigeon-pea and sunn-hemp pathogens might readily be obtained together in cultures and might be expected to infect both hosts. Thus we have one possible explanation of the divergence of results obtained by various workers, some of whom have found the pigeon-pea and sunn-hemp organisms highly specific whereas others have found that they possess an infective range of several hosts.

One other curious and highly interesting observation may be made here. It will be seen that the highly pathogenic forms made poor or, at best, moderate growth on the mixture of soil and cornmeal used as inoculum. On the other hand, the organisms which caused a much lower percentage of wilting grew well in the flasks, all three of the less effective sunn-hemp organisms

having ramified the soil and producing considerable ærial mycelium. The full significance of these facts will become clear in the next contribution of this series which will, to a large extent, resolve the confusion at present existing with regard to the taxonomy of these fungi.

Summary

1. Cultures of *Fusarium* were isolated from cotton (*Gossypium* sp.), pigeon-pea (*Cajanus cajan*) and sunn-hemp (*Crotalaria juncea*). Fifty-one such isolates were tested for their pathogenicity against all three hosts.

2. Most of the cotton isolates failed to cause wilt, but a number of them caused low germination by attacking and destroying the seeds. Some isolates produced this effect on cotton, others on pigeon-pea, and yet others on sunn-hemp or on two or three of these.

3. As regards wilt there was a high degree of specificity and few if any cases of wilt resulted from these inoculations. Two isolates from sunn-hemp were specific for pigeon-pea.

4. The isolates causing severest wilting were those which grew least vigorously on the mixture of soil and maizemeal used for infesting the soil.

REFERENCES

Butler, E. J. (1918). *'Fungi and disease in plants'* : Thacker, Spink and Co., Calcutta and Simla

Hansford, C. G. (1939). *Rept. Dept. Agric., Uganda (Part II) Year ended 30th June 1938*, 20-25

Mitra, M. (1934). *Ind. J. Agri. Sci.* **4**, 701-14

Padwick, G. W. (1939). *Ind. J. Agric. Sci.* **9**, 171-84

Small, W. (1920). *Kew Bull.*, 321-8

———— (1922). *Kew Bull.*, 269-91

———— (1925). *Kew Bull.*, 118-26

Uppal, B. N. and Kulkarni, N. T. (1937). *Ind. J. Agric. Sci.* **7**, 413-42

Vincens, M. F. (1921). *Bull. Agric. de l'Inst. Sci. de Saigon* **3**, 381-4

SUGARCANE VARIETAL TRIALS IN THE DECCAN CANAL-TRACT AT PADEGAON, 1933-1938

BY

B. P. VAGHOLKAR, L.Ag. (Bom.)

Principal Agricultural Officer, Sugarcane Research Scheme, Bombay-Deccan-Padegaon*

AND

N. B. PATWARDHAN, B.Ag. (Bom.)

Agricultural Overseer

(Received for publication on 27 September 1938)

(With Plates XXX—XXXII and two text-figures)

Introduction

IN India cane is grown under varying conditions of soil and climate either with irrigation or without irrigation but under well-distributed rainfall during a single monsoon or two monsoons. In the Deccan canal-tract, owing to the very scanty rainfall it is grown under irrigation throughout the year and very high yields are recorded.

Before the commencement of the Sugarcane Research Scheme at Padegaon with the munificient grant from the Imperial Council of Agricultural Research, a collection of canes from different parts of the world, like Queensland, Mauritius, Java, Barbados, Hawaii and from India—as Hebbal-Mysore and Coimbatore—was made and grown in the museum for study for a number of years at Manjri, the oldest sugarcane experimental station, near Poona.

Flowering varieties were not much in favour with the cultivators as they failed to supply the green tops, so very necessary for feeding the bullocks used for crushing the cane, in the course of *gul* manufacture. Some of the flowering varieties—like Manjav (B 376), D 109, J 213, J 36, Str. D 109, B 208, B 1528, H 109, HM 337 and the non-flowering canes HM 544, HM 310, HM 89—were under final trial at Manjri as well as at the two substations at Baramati and Kopergaon on the Deccan canals.

The varietal trials till 1925 have been well described by Patil and Patwardhan [1925]. Subsequent to 1925, the varieties POJ 2878 and EK 28 were brought under trial and after four years' testing, the variety POJ 2878 was supplied to the Belapur Sugar Factory and EK 28 was introduced among the cane-growers.

Out of these varieties, only D 109, HM 544 and HM 89 spread a little among the cultivators till the introduction of EK 28 and POJ 2878 in 1931. These varieties being of rather high fibre-content spread mostly among the cultivators with power crushers.

From this period onwards, with the passing of the Tariff Act by the Government of India, the aspect however changed owing to the rapid springing

* This scheme is partly subsidised by the Imperial Council of Agricultural Research.

up of the sugar factories. The breeding work on the noble canes which was started at Coimbatore in 1926 had also evolved a number of selections with promise of success. Hence the selection work described in this paper comprises trials both for the factories and the cultivators.

SOIL

Padegaon Sugarcane Research Scheme is situated on the Nira Right Bank Canal in Satara district, about forty five miles from Poona on the old Poona-Satara Road, elevation above sea-level being 1804 ft. The soil belongs to the group of black cotton soil which is further classified by Basu and Sirur [1938] by the modern genetic method into distinct types. The soil of the farm falls under the type ' B ', and is described as follows :—

> 'Dark grey soil rich in clay up to a depth of two feet overlying a layer with lighter texture interspersed with patches of brown material, extending up to about four feet. Below this is a brownish red horizon with similar texture with concretions of calcium carbonate and silicates. This layer varies in depth and usually goes up to murum.'

The sub-soil water-level is found to fluctuate between 6 and 10 ft.

METEOROLOGY

Average rainfall of the place is only 18 in. but most of it comes in September and October. There is also a great variation from year to year as has been shown in Table I. The highest maximum and the lowest minimum temperatures ever reached within the five years are 109°F. and 37·5°F. respectively with the average wind velocity of 7·34 miles per hour from April to September (the maximum being 9·05 miles per hour in May) within which period it is at its maximum. Full data for five years are graphically illustrated in Figs. 1 and 2.

Owing to sporadic nature of rainfall distribution and its insufficient quantity, the cane is required to be grown with irrigation water from canals from the time of planting till harvest, during which period nearly thirty-four to thirty-five irrigations at ten-day interval are to be given. In spite of this controlled irrigation, it is traced that deviation in climate does influence cane-growth and in the end affects the yield. In Northern India and the United Provinces the critical periods are (1) hot summer and (2) winter, characterised by want of moisture in the former and by frost in winter of varying degrees in rigours, as the crop there is mainly rain-fed. But under Padegaon conditions the critical periods occur during monsoon when the growth-period of cane is spread, and are dependent upon rainfall, specially its distribution which influences humidity required for growth during the period. These periods can be grouped into three distinct ones and their normal characteristics are enumerated below :—

(1) First period—Mid-May to June :
Characterised by ante-monsoon showers in May followed by normal weather in June, quantity of rainfall is of no consideration.

(2) Second period—July and August :
Characterised by small quantities of rainfall in which case its long range distribution is an important factor as against quantity.

(3) Third period—September :
Characterised by sultry climate precursory to rain and high rainfall.

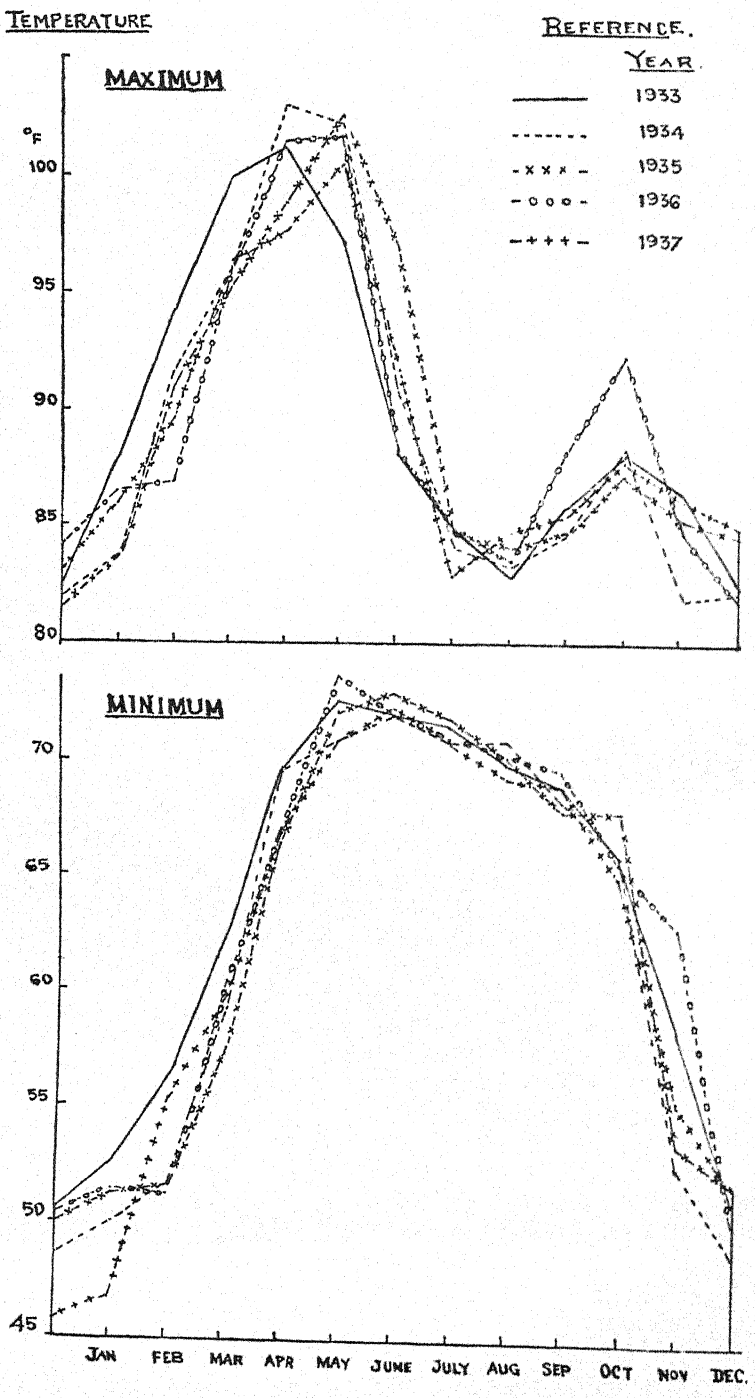


FIG. 1. Meteorological data (temperature), 1933-37

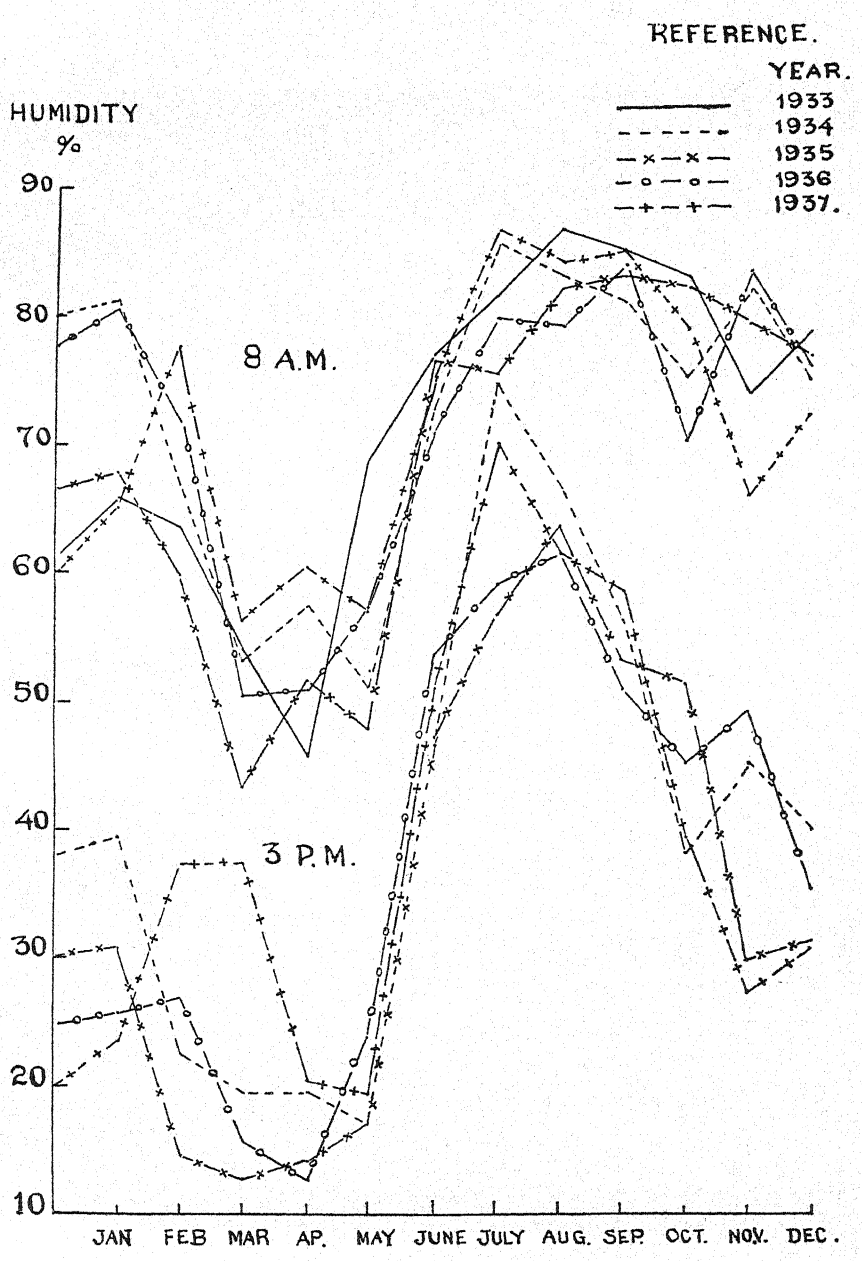


FIG. 2. Meteorological data (humidity), 1933-37

TABLE I

Rainfall and number of rainy days (1933-37)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
						Rainfall in inches							
1933	..	..	0·18	..	0·94	2·74	2·60	3·66	4·69	1·30	1·07	0·75	17·93
1934	..	..	0·18	0·66	1·27	3·57	1·84	1·16	2·70	4·06	5·57	..	21·01
1935	..	..	..	..	..	2·66	0·90	6·47	1·37	6·60	..	0·36	18·36
1936	..	0·26	1·75	..	2·43	2·01	0·14	0·77	4·58	0·05	1·92	..	13·91
1937	..	0·21	..	1·92	0·22	2·78	3·47	0·28	8·59	2·49	..	0·46	20·92
						No. of rainy days							
1933	..	..	2	..	5	13	10	11	14	11	5	2	73
1934	..	..	1	3	2	10	16	10	6	7	3	..	58
1935	..	..	..	..	..	10	8	11	5	14	..	1	49
1936	..	1	2	..	4	5	5	8	10	1	6	..	42
1937	..	2	..	3	2	8	18	8	13	7	..	2	63

Materials and methods

During the period from 1931-37, five dozen thick and thin seedling canes were received from Coimbatore and half a dozen from Hebbal-Mysore. These formed the basis of selection work and the promising selections, details of which are given in the subsequent pages, have been obtained from this collection.

The work of selection, in the preliminary, prefinal and final varietal trials had to be expedited in order to enable early release of these varieties for testing with the cultivators and the factories in different soil types. The following policy was adopted.

(*a*) When the varieties were received, these were multiplied in the first year, tested in prefinal trial for a year or two during which period they acclimatized ; and if during this period any variety showed outstanding performance, it was taken into final trial.

(*b*) In the final trial the prominent varieties were tested with control varieties like Pundia, POJ 2878 and EK 28, both from sugar and *gul* point of view in replicated trials. In all the trials at Padegaon the manurial dose of 150 lb. nitrogen is maintained. Three years' period was fixed for a thorough trial but if it was traced that even within two years any one showed outstanding superiority over the control ones it was liberated for multiplication and trials outside.

The following were the criteria for selecting a variety for the Deccan conditions and any variety which stood to these criteria, was finally selected for liberation for trials outside :

(1) Good germinative capacity.
(2) Stooling capacity and character of resisting adverse season.
(3) A fair immunity to pests and diseases.
(4) Tendency to less shooting and forming pith incident to arrowing.
(5) Efficient root-system from the stand-point of securing maximum value from fertilizers applied to the land.
(6) Ease of stripping or trashing.
(7) Early or late maturity and keeping quality in the field after maturity.
(8) High sucrose.
(9) High tonnage.

Experimental

The varietal trials in the following pages have been classified into four experiments as below :—

Experiment I : Medium-late varietal trials, 1933-34 to 1935-36.
Experiment II : Medium-late varietal trials, 1935-36 to 1937-38.
Experiment III : Early varietal trials including sugarcane-sorghum hybrids, 1934-35 to 1936-37.
Experiment IV : October planting trials, 1934-35 to 1936-37.

Experiment I

Trial of medium-late varieties, 1933-34 to 1935-36

In this three-year period, the control varieties grown alongside with other varieties were Pundia, POJ 2878 and EK 28 ; the first of these control

varieties is the non-flowering, cultivator's favourite cane for *gul*-making and the latter two flowering are mainly factory canes with high sugar content.

Year 1933-34.—This was the first year of trial; from amongst the first two batches of Co varieties (viz. Cos 358 to 365 except Co 359 and Cos 400 to 415) the varieties Co 360 and Co 402 which showed promise from only growth characters were taken together with the new addition of HM 320 from Hebbal-Mysore. In addition to these, the varieties Co 290, HM 89, Str. D 109 and H 109 which had shown good performance at Manjri Farm were also included. All these are flowering varieties except HM 89 and HM 320.

The old canes Str. D 109, H 109 and HM 89 fared badly in comparison with the new arrivals; the first two show abnormal fluctuation in germination from season to season and have low sugar content. HM 89 produces abnormal bunches of tillers which exercise a check on normal cane growth, but it is a cane of high sugar content and for specific tracts.

Year 1934-35.—The varieties H 109 and Str. D 109 were therefore discontinued. Among the other varieties, Co 360 has equalled POJ 2878 in yield as in the previous year. Co 402 has extreme fluctuation in flowering from year to year, which has been reflected in its yields; yet it issignificant over EK 28.

Year 1935-36.—HM 89 is dropped as it had a thorough trial for a long period at Manjri (for seven years) and even at Padegaon. The only new additions are Co 419, Co 413 from early group and Co 412. Among the varieties tried during the last two years, HM 320 has shown highly significant performance over the control varieties; whilst Co 360 and Co 290, even though not surpassing POJ 2878, have again shown significantly high yields over EK 28 and Pundia.

The three years' data of cane and commercial cane sugar per acre is presented in Table II year by year. In the following pages, commercial cane sugar has been arrived at as per formula recommended by the Director, Imperial Institute of Sugar Technology, which is reproduced below for ready reference :—

$$\text{C. C.} = \frac{3\,P}{2}\left(1-\frac{10+F}{100}\right)-\frac{B}{2}\left(1-\frac{6+F}{100}\right)$$

Where P=Polarisation in first expressed juice.

B=Brix in first expressed juice.

F=Fibre in cane.

The varieties Co 290, Co 360, Co 402 and HM 320 have completed the three years' test in the final trial in comparison with the three control varieties, POJ 2878, EK 28 and Pundia.

Some of these promising varieties have been illustrated in Plates XXX and XXXI.

Detailed studies were carried out with regard to these varieties from standpoint of their developmental characters and these are discussed below.



Co 290 Co 360 Co 412 Co 413 Co 414 Co 419 POJ 2878 Pundia EK 28

January planting : age of crop $10\frac{3}{4}$ months

January planting : age of crop $10\frac{3}{4}$ months

TABLE II

Yield of millable cane and commercial cane sugar in tons per acre
(Data for three seasons)

	Name of variety										General mean	S. E. of treatment mean	Whether general effect of treatment significant by *z*-test	Critical difference for significance
	Co 290 (tons per acre)	Co 360 (tons per acre)	Co 402 (tons per acre)	HM 320 (tons per acre)	POJ 2878 (tons per acre)	EK 28 (tons per acre)	Pundia (tons per acre)	HM 89 (tons per acre)	H 109 (tons per acre)	Str. D 109 (tons per acre)				
1933-34														
Cane	42·54	36·72	43·59	39·86	36·61	30·07	37·96	26·97	31·07	33·90	35·85	2·42	Significant	6·74
C. C. sugar	5·22	5·29	4·38	4·17	5·31	3·83	4·48	3·83	3·80	3·92		Not calculated statistically		
1934-35														
Cane	42·68	40·53	36·48	47·13	40·72	30·97	29·44	38·39			38·30	2·01	Significant	5·55
C. C. sugar	5·32	4·89	3·96	5·72	5·67	4·39	3·91	5·63				Not calculated statistically		
1935-36														
	Co 290	Co 360	Co 402	H M 320	POJ 2878	E K 28	Pundia	Co 412	Co 413	Co 419				
Cane	42·75	40·47	47·61	46·43	44·07	36·59	33·81	34·65	46·89	56·20	42·95	1·42	Significant	3·98
C. C. sugar	5·39	5·56	4·27	5·42	6·33	5·21	4·06	4·33	5·99	7·16		Not calculated statistically		

Conclusions :—1933-34—Co 402 Sig. > POJ 2878, EK 28
1934-35—H M 320 Sig. > POJ 28 8. Co 290 > POJ 2878=Co 360 Sig. > EK 28 and Pundia
1935-36—Co 419 Sig. > Co 402, Co 413 Sig. > Co 290, Co 419, Co 413, HM 320 Sig. > E K 28 and Pundia

Germination.—The new Co varieties have not shown much superiority in germination over the control varieties (Table IV). Rege and Wagle [1939] have shown the deleterious effect of minimum temperature below 50°F. on the rapidity of germination and these temperatures were prevalent during the first three weeks of the seasons 1934 and 1935. As a result of this, the total germination during both these years was retarded.

Borer attack.—The chief pest of the Deccan is a sugarcane borer (*Argyria sticticraspis*) ; the infestation is the highest in April and May. The incidence of the pest as recorded in different varieties in May shows that the varieties Co 290, Co 360 and HM 320 are comparatively more resistant to the attack than EK 28 and Pundia.

Mealy bug is the pest second in importance ; its presence is restricted only to the variety Co 360 which has closely adherent leaf sheaths.

Periodical changes in tillering.—Table III shows the progressive increase in the number of tillers from eighth week till harvest for a four-cent plot (1/25th of an acre) wherein 1200 buds were planted (equivalent to 30,000 buds per acre).

TABLE III

Total shoot counts

(Average of 6 plots, each plot = 4 cents)

Average of two years

Variety	At 8 weeks (germination)	Before earthing up (5½ months)	After earthing up		At harvest		
			7½ months	Percentage of success on before earthing-up count		Percentage of success on before earthing-up count	Tons of cane per acre
Co 290 .	665	3836	1998	52·1	1833	47·8	42·7
Co 360 .	563	1830	1342	73·3	1256	68·6	40·5
Co 402 .	726	3867	1605	41·5	1311	33·9	42·0
HM 320 .	702	2750	1412	51·3	1016	36·9	46·7
POJ 2878	780	2362	1445	61·2	1280	54·2	42·4
EK 28 .	689	1881	1026	54·4	852	45·3	33·8
Pundia .	617	2135	1234	57·8	900	42·1	31·6

The data in Table III, when reduced to the number of shoots obtained per 100 planted buds (Table IV) at different periods, clearly reveal the

situation regarding high or low tillering, and its success at harvest time obtaining in the different varieties. Table IV also shows the percentage of borer-attack.

TABLE IV

Germination and borer attack per cent and ratio of number of shoots on 100 planted buds

Variety	Germination per cent at 8 weeks	Borer attack per cent	Before earthing up	After earthing up	At harvest
Co 290 . .	55·4	4·5	319·7	166·5	152·7
Co 360 . .	46·9	7·2	152·5	111·8	104·7
Co 402 . .	60·5	4·2	322·2	133·7	109·2
HM 320 . .	58·5	5·9	229·2	117·7	84·7
POJ 2878 .	65·0	5·3	196·8	120·4	106·7
EK 28 . .	57·4	10·9	156·7	85·5	71·0
Pundia . .	51·4	11·9	177·9	102·8	75·0

The tables reveal the following special features in tillering :—

(1) High, medium and low tillering in the different varieties.
(2) Maximum and minimum losses of tillers after earthing-up.
(3) Similar maximum and minimum losses between the two periods — after earthing up and at harvest.

All these three will greatly influence the utilisation of manure at different stages, and where the bill of manuring is high this type of information is very important.

It would thus be seen that the production of a large number of tillers as in Co 402 would not be the main criterion for judging the suitability of any variety, but the final successful tillers, coupled with individual weight per cane, would also require consideration. Thus varieties with even mediocre number of canes at harvest coupled with good yields as in Co 360 and POJ 2878 would be efficient varieties although they may be low in tillering.

Next in order will be the variety which gives high tillering with as high a yield as the variety in the first group, although the percentage success of tillers produced may be low. From both these standpoints, the best varieties are Co 360 and POJ 2878 and next to these are Co 290, Co 402 and HM 320. So far as EK 28 and Pundia are concerned, they do not come up to the standard of both of these, as they possess both low tillering capacity and yield.

Habit.—The varieties Co 360 and Co 290 are found to possess very good habit of growth being erect to slightly sub-erect ; so are the varieties POJ

2878 and EK 28. The varieties HM 320 and Pundia were found to be sub-erect to slanting, the variety Co 402 being much more slanting and reclining than others.

With very vigorous growth, the varieties Co 360 and Co 402 tended to lodge in varying intensities, owing only to cyclonic effects which occur specially in September when they have attained the maximum growth. As compared to other varieties, Co 360 was found to be difficult for stripping owing to adherence of sheaths.

Flowering.—Out of the total number of millable canes obtained in each of the different varieties, the number of flowering canes varies with the different varieties. The percentage of flowering canes in the different varieties, as recorded in the year 1935, is given in Table V.

TABLE V

Flowering data

Serial No.	Variety	Percentage of flowering	
1	Co 290	61·9	
2	Co 360	73·5	
3	Co 402	16·3	Recorded on 23rd December 1935
4	HM 320	Non-flowering	
5	POJ 2878	84·9	
6	EK 28	85·4	
7	Pundia	Non-flowering	

Root-system.—The root-exposure studies of the different varieties have shown that excepting Co 360 and Pundia most of them have an efficient root-system having good penetration and lateral spread. Pundia especially has the most superficial and smallest volume of root-system of all the varieties studied.

March of ripeness.—Table VI show the data of brix and purity from October to March, month by month.

The data in Table VI when briefly summarised show the position in regard to the different varieties as to when the ripeness commences and the duration over which it is maintained (Table VII). Information regarding the average weight per cane and sucrose and fibre per cent in cane is also included in Table VII.

TABLE VI

March of ripeness

Month	Co 290		Co 360		Co 402		HM 320		POJ 2878		EK 28		Pundia	
	1934	1935	1934	1935	1934	1935	1934	1935	1934	1935	1934	1935	1934	1935
						Brix								
October	16·13	15·26	18·47	14·73	15·20	12·61	15·26	12·16	18·17	15·38	16·35	16·73	13·39	11·96
November	18·17	18·81	19·91	16·84	17·18	14·10	17·32	14·19	20·25	18·42	18·16	18·86	15·39	12·58
December	20·56	21·27	21·22	18·78	17·18	16·83	18·72	15·42	21·96	21·01	19·22	20·62	17·05	15·32
January	21·35	21·88	22·24	19·58	19·05	17·15	19·07	16·43	22·54	21·97	21·01	21·64	17·93	14·89
February	21·63	21·49	21·74	21·43	18·53	19·36	19·93	17·73	22·24	22·41	21·06	21·28	19·34	18·26
March	21·50	20·43	20·06	19·94	18·37	18·78	20·20	17·56	21·11	21·38	21·46	22·11	20·16	17·63
						Purity								
October	..	75·90	..	75·61	..	70·81	..	61·35	..	74·98	..	82·31	..	61·70
November	..	83·79	..	82·24	..	77·11	..	73·86	..	82·56	..	87·54	..	63·51
December	90·74	88·41	92·53	87·54	88·41	78·66	89·91	79·12	90·22	90·53	92·00	90·86	86·14	75·13
January	89·69	90·36	91·98	90·67	90·69	88·69	91·01	87·40	91·75	92·41	92·30	90·90	89·66	81·25
February	91·16	89·35	91·16	90·72	89·32	91·89	90·20	88·59	91·62	92·51	90·69	91·73	89·48	86·42
March	91·41	87·64	89·71	89·17	88·06	88·82	91·18	87·26	92·02	91·42	92·55	91·81	91·60	85·72

TABLE VII

Serial No.	Variety	Commencement of ripeness	Duration over which ripeness is maintained	In cane at maximum maturity		Average weight per cane lb.
				Sucrose per cent	Fibre per cent	
1	Co 290	January	Mid-March	15·20	14·98	2·22
2	Co 360	January	February	16·43	12·54	2·97
3	POJ 2878	Mid-December	February	16·73	13·77	3·15
4	HM 320	February	March	13·58	13·45	4·15
5	Co 402	February	March	12·05	15·90	3·07
6	EK 28	February	March	16·21	12·50	3·52
7	Pundia	February	March	14·84	10·39	3·13

Co 290 shows equal sugar and fibre content. Co 360 and HM 320 show less fibre, but the former equals POJ 2878 and EK 28 in sucrose and is better than Pundia. Co 402 has very low sugar content. This data is useful in understanding the varieties suitable for cultivators and the factories.

Relative yield performance with the control varieties.—The study of the above characters is clearly reflected in the final yield of cane, *gul* and commercial cane sugar, which could be seen from Table VIII where Pundia, POJ 2878 and EK 28 are taken as 100 and the final performance calculated accordingly.

TABLE VIII

Relative yield performance of the varieties

(*Average of three seasons*)

Per acre	Co 290	Co 360	Co 402	HM 320	POJ2878	EK 28	Pundia
			Cane				
Tons	42·66	39·24	42·56	44·47	40·47	32·54	33·74
Percentage on Pundia	126·5	116·2	126·2	131·8	119·9	96·45	100·0
Percentage on POJ 2878	105·4	96·94	105·2	109·8	100·0	80·39	83·35
Percentage on EK 28	131·1	120·6	130·8	137·0	124·4	100·0	103·7

TABLE VIII—*contd.*

Per acre	Co 290	Co 360	Co 402	HM 320	POJ2878	EK 28	Pundia
			Gul				
Tons	4·58	4·33	3·85	4·52	4·49	3·84	3·76
Percentage on Pundia	121·8	115·2	102·4	120·1	119·4	102·1	100·0
Percentage on POJ 2878	102·1	96·45	85·76	100·7	100·0	85·53	83·75
Percentage on EK 28	119·3	112·8	100·2	117·7	116·9	100·0	97·92
			Commercial cane sugar				
Tons	5·31	5·24	4·20	5·10	5·75	4·48	4·15
Percentage on Pundia	127·9	126·3	101·2	122·9	138·6	108·0	100·0
Percentage on POJ 2878	92·34	91·11	73·03	88·59	100·0	77·91	72·16
Percentage on EK 28	118·5	116·9	93·74	113·9	128·3	100·0	92·65

Conclusions.—The varieties Co 360 and Co 402 are significantly better than Pundia and EK 28 in cane-yield. Co 360 is a mid-late cane, having adherent trash and subject to lodging. Co 402 is very erratic in behaviour and low in sugar-content. Co 290 and Co 360 have almost equal performance with POJ 2878 in cane-yield. HM 320 is a late-maturing, flower ess cane and subject to lodging.

The *gul* yields of Co 360 and HM 320 are almost significantly high in comparison with the control varieties, Pundia and EK 28, and almost equivalent in merit to POJ 2878. Most of the varieties except Co 402 are superior to Pundia and EK 28 from standpoint of commercial cane sugar. The varieties Co 290, Co 360 and HM 320 are next best to POJ 2878.

EXPERIMENT II

Medium-late varietal trials, 1935-36 to 1937-38

During this three-year period, the control varieties were POJ 2878 and Pundia ; EK 28 was grown as control in 1935-36 only and further discontinued owing to its inadaptability to the environmental conditions.

Year 1935-36.—In this year the new additions were Co 419, Co 412 and Co 413.

Co 419 has shown high significance over the three contro varieties. Co 413 is not significantly better than POJ 2878 but it is significant over EK 28 and Pundia.

Year 1936-37.—The selections Co 290, Co 360, Co 402 and HM 320 having completed three years' trial were discontinued; in addition to the varieties mentioned above, five new selections—Co 414, Co 416, Co 417, Co 421 and Co 426—were included (Plate XXXI).

The varieties Co 419, Co 413, Co 416, Co 421 and Co 426 show highly significant yield over the control varieties. Co 416 in spite of its exceptionally high tonnage is traced to be very low in sugar content like Co 402 in experiment I.

Year 1937-38.—The varieties Co 412 and Co 416 were dropped and the remaining varieties were continued. All the Co selections have given significantly higher yield than POJ 2878 and Pundia.

The cane varieties Co 419 and Co 413 have completed three years' trial. The three years' data of cane and commercial cane sugar per acre are presented in Table IX year by year.

As stated above, the cane varieties were studied from standpoint of their developmental characters and these are discussed below.

Germination.—Co 419 gives early and higher germination compared to other varieties. In point of rapid and maximum germination, Co 419 surpasses the control varieties and the next is Co 413.

Borer attack.—The varieties Co 419 and Co 413 have practically the same borer attack as POJ 2878. All these three are more resistent than Pundia. No other pest is present on these varieties (Table XI).

Periodical changes in tillering.—Table X shows the progressive increase in the number of tillers from eighth week till harvest for a four-cent plot (1/25th of an acre), wherein 1200 buds were planted (equivalent to 30,000 buds per acre).

The data in Table X, when reduced to a ratio of number of shoots obtained for 100 planted buds (Table XI) at different periods, clearly reveal the situation regarding high or low tillering, obtaining in the different varieties. Data regarding percentage of germination and borer attack in the different varieties is also given in Table XI.

Rapidity in germination obtained in Co 419 and Co 413 is further reflected in their early and high tillering and also large number of successful canes obtained at harvest compared to the control varieties.

Habit.—Varieties Co 419 and Co 413 possess very good habit of growth, being mostly erect.

Flowering.—The percentage of flowering canes in different varieties as recorded on the 23rd of December 1935 was as shown in Table XII.

Root-system.—Varieties Co 419 and Co 413 have an efficient root-system having both better penetration and lateral spread than POJ 2878. Pundia has the most superficial root-system and the volume of root-system is the least compared to other varieties.

March of ripeness.—Table XIII shows the data of brix and purity from October to March, month by month.

The summary in Table XIV shows when ripeness commences in these varieties and the duration over which the juice-quality is maintained; the data regarding the average weight per cane, sucrose and fibre-content in cane is also included.

TABLE IX

Yield of millable cane and commercial cane sugar in tons per acre

(Data for three seasons)

	Name of variety										General mean	S. E. of treatment mean	Whether general effect of treatment significant by *z*-test	Critical difference for significance
	Co 290 (tons per acre)	Co 360 (tons per acre)	Co 402 (tons per acre)	H M 320 (tons per acre)	POJ 2878 (tons per acre)	EK 28 (tons per acre)	Pundia (tons per acre)	Co 412 (tons per acre)	Co 413 (tons per acre)	Co 419 (tons per acre)				
1935-36														
Cane	42·75	40·47	47·61	46·43	44·07	36·59	33·81	34·65	46·89	56·20	42·95	1·42	Significant	3·98
C. C. sugar	5·39	5·56	4·27	5·42	6·33	5·21	4·06	4·33	5·99	7·16		Not calculated statistically		
1936-37														
	Co 414	Co 416	Co 417	Co 421	POJ 2878	Co 426	Pundia	Co 412	Co 413	Co 419				
Cane	38·09	50·13	32·56	40·87	28·95	43·19	30·16	32·36	45·86	44·96	38·72	2·08	Significant	5·82
C. C. sugar	5·0	4·36	3·97	4·88	3·99	4·94	3·59	3·59	5·38	6·19		Not calculated statistically		
1937-38														
	Co 414	Co 419	Co 417	Co 421	POJ 2878	Co 426	Pundia	Co 413						
Cane	37·76	44·58	39·21	41·29	29·38	44·41	24·44	42·57			37·96	2·47	Significant	7·06
C. C. sugar	5·33	6·41	4·86	5·11	4·43	5·36	3·02	5·53				Not calculated statistically		

Conclusions :—1935-36—Co 419 Sig. > Co 402, Co 413 Sig. > Co 290 ; Co 419, Co 413, HM 320 Sig. > EK 28, Pundia
1936-37—Co 416 > Co 413=Co 419 > Co 426 > Co 421 > Co 414 Sig. > Pundia and others
1937-38—Co 419, Co 426, Co 413, Co 421, Co 414 Sig. > POJ 2878 and Pundia

TABLE X

Total shoot counts

(Average of 6 plots, each plot=4 cents average of three years)

Variety	At 8 weeks	Before earthing up	After earthing up	Percentage of success on before earthing-up count	At harvest	Percentage of success on before earthing-up count
Co 419	900	2946	1855	62·9	1539	52·2
Co 413	892	4047	2076	51·3	1648	40·7
POJ 2878	791	2323	1448	62·3	1195	51·4
Pundia	744	2252	1445	64·2	883	39·2

TABLE XI

Percentage of germination, borer attack and ratio of number of shoots for 10 planted buds

Variety	Germination per cent at 8 weeks	Borer attack per cent	Before earthing up	After earthing up	At harvest
Co 419	75·0	4·4	245·5	154·6	128·2
Co 413	74·3	4·1	337·2	173·0	137·3
POJ 2373	65·9	4·6	193·6	120·7	99·6
Pundia	62·0	8·9	187·7	120·4	73·6

TABLE XII

Flowering data

Serial No.	Variety	Percentage of flowering
1	Co 419	82·4
2	Co 413	80·1
3	POJ 2878	84·9
4	Pundia	Non-flowering

TABLE XIII

March of ripeness

	Co 419			Co 413			POJ 2878			Pundia		
	1935	1936	1937	1935	1936	1937	1935	1936	1937	1935	1936	1937
						Brix						
October	12·59	12·80	16·10	12·86	15·04	17·15	15·38	17·23	17·72	11·96	11·55	14·17
November	15·59	16·83	18·66	15·93	17·83	19·56	18·42	21·29	20·49	12·58	14·01	14·66
December	19·52	18·99	21·40	17·87	19·57	21·10	21·01	21·92	22·28	15·32	15·68	17·66
January	20·21	20·84	21·93	17·04	20·05	21·14	21·97	22·28	22·68	14·89	18·00	18·00
February	21·58	20·63	21·82	18·16	20·43	20·98	22·41	21·19	22·31	18·26	18·64	19·71
March	20·98	20·39	20·35	19·43	19·76	19·45	21·38	22·11	20·55	17·63	20·42	19·40
						Purity						
Octobe	65·86	67·35	79·02	69·97	78·47	84·68	74·98	79·00	82·22	61·70	60·09	75·40
November	77·29	80·39	86·34	81·04	85·13	90·35	82·56	89·60	88·98	63·51	71·24	78·77
D ecember	86·30	83·79	90·35	85·74	88·94	91·81	90·53	90·95	91·62	75·13	75·08	86·92
January	85·49	87·14	90·80	86·06	89·50	92·32	92·41	91·83	90·88	81·25	84·50	87·16
February	91·22	88·37	93·11	88·59	89·30	93·09	92·51	92·10	92·92	86·42	88·47	91·43
March	90·84	88·72	92·28	87·68	90·28	91·77	91·42	92·26	91·11	85·72	90·76	90·65

TABLE XIV

Serial No.	Variety	Commencement of ripeness	Month up to which ripeness is maintained	In cane at maximum maturity		Average weight per cane lb.
				Sucrose per cent	Fibre per cent	
1	Co 419	February	March	16·04	13·86	2·97
2	Co 413	January	March	14·6	16·66	2·37
3	POJ 2878	December	February	16·54	16·35	2·64
4	Pundia	February	March	14·438	11·61	2·95

The variety Co 419 is slightly less in sucrose content than POJ 2878 and is also comparatively less hard than POJ 2878. The varieties Co 419 and Co 413 were found to record very steady weight per cane during the three years' testing compared to the control varieties and an increased weight per cane over POJ 2878.

Relative yield performance with the control varieties.—The comparative value of these Co varieties from standpoint of cane, *gul* and commercial cane sugar taking POJ 2878 and Pundia as 100 is presented in Table XV.

TABLE XV

(*Average of three years 1935-37*)

Per acre	Co 419	Co 413	POJ 2878	Pundia
		Cane		
Tons	48·58	45·11	34·13	29·47
Percentage on POJ 2878	142·30	132·10	100·00	86·32
Percentage on Pundia	164·80	153·10	115·80	100·00
		Gul		
Tons	5·59	4·66	4·03	3·38
Percentage on POJ 2878	138·7	115·6	100·00	83·87
Percentage on Pundia	165·4	137·9	119·20	100·00
		C. C. Sugar		
Tons	6·59	5·63	4·92	3·56
Percentage on POJ 2878	134·00	114·40	100·00	74·03
Percentage on Pundia	185·10	158·10	138·20	100·00

Conclusions.—The varieties Co 419 and Co 413 are outstandingly superior to POJ 2878 and Pundia from standpoint of cane, *gul* and sugar. The varieties Co 413 and Co 419 have got very good root-system and erect habit of growth. Co 413 is very nearly a mid-late cane and Co 419 is mid-late to late in maturity. Co 413 produces *gul* of superior quality and Co 419 is the next best. Co 419 has almost the same sucrose-content in cane as POJ 2878.

EXPERIMENT III

Early varietal trials including sugarcane, sorghum hybrids, 1934-35 to 1936-37

When the cane selection work was commenced in 1933, it was observed that some of the selections showed maturity even at the tenth month ; hence these were separately grouped and tested as early varieties. In the same year, the sugarcane-sorghum hybrids which were reported to mature within six months were also received. So a combined trial consisting of the early varieties Co 407, Co 408, Co 411, Co 413 and HM 606 together with the six sugarcane-sorghum hybrids Co 351 to Co 357 (except Co 354) was undertaken. Replicated and randomised layout was adopted as in the final varietal test with a smaller plot-size and three feet distance between rows instead of four feet. The manurial dose was 150 lb. nitrogen as in the above experiments. The soil of this block where these tests were conducted had lower fertility trend as compared to the soil in which varieties described in experiments I and II were tested.

POJ 2878 was grown as a control variety throughout this period, and Co 360 during the latter two years only.

Year 1934-35.—In this year, varieties Co 407, Co 408, Co 411, Co 413 and HM 606 together with Co 351 to 357 (except Co 354) were under trial.

The yield performance of Co 413, Co 408, HM 606, Co 352, Co 355 and Co 356 are almost equal to or slightly better than POJ 2878. From maturity point of view Co 411 and Co 407 have shown indications of earliness. Sugarcane-sorghum hybrids begin to mature from tenth month onwards.

Year 1935-36.—As the variety Co 413 was found to be late it was transferred during this year in the final trial described in experiment II. HM 606 was discontinued as it was a lodging variety with low sucrose-content.

As in the previous year, none of the varieties are significantly better than POJ 2878 ; however the sugarcane-sorghum hybrids Co 352, Co 353 and Co 356 have yielded slightly higher than POJ 2878.

The varieties Co 407 and Co 411 show maturity from tenth month onwards (as in the previous year). Amongst the sugarcane-sorghum hybrids the earliest to mature are Co 351 and Co 352 ; the remaining varieties ripen between ten and eleven months.

Year 1936-37.—As a result of the data available for the last two years, only Co 352, Co 353 and Co 356 amongst sugarcane-sorghum hybrids were continued for trial, together with early varieties to which Co 421 was added.

The varieties Co 360, Co 421 and Co 408 have yielded significantly better than POJ 2878. Co 411 is almost significant over POJ 2878. Co 407 is equal in performance to POJ 2878.

The cane-sorghum hybrid Co 356 is significantly better than POJ 2878 and Co 352 and Co 353 have yielded as much as POJ 2878.

The cane varieties Co 360 and Co 421 show ripeness from tenth month onwards.

The cane-sorghum hybrids do not even show the start of maturity earlier than 8½ months ; definite trend towards maturity is seen only after 9½ or 10 months.

The three years' data of cane per acre are presented in Table XVI year by year.

TABLE XVI

Yield of millable canes in tons per acre
(Data for three seasons)

Yield												General mean	S. E. of variety mean	Whether general effect of treatment sig. by z-test	C. D. for significance
Co 407	Co 408	Co 411	Co 413	HM 606	Co 351	Co 352	Co 353	Co 355	Co 356	Co 357	POJ 2878				
							1934-35								
31·0	35·44	31·58	36·12	36·48	30·98	37·07	31·67	36·29	37·48	31·84	34·39	34·32	3·03	Not significant with POJ 2878 as control	8·92
							1935-36								
Co 407	Co 408	Co 411	Co 360		Co 351	Co 352	Co 353	Co 355	Co 356	Co 357	POJ 2878				
27·51	27·74	25·17	30·35		22·59	29·16	31·46	26·77	29·74	27·67	28·10	27·88	1·45	Not significant with POJ 2878 as control	4·29
							1936-37								
Co 407	Co 408	Co 411	Co 360	Co 421		Co 352	Co 353	Co 356			POJ 2878				
29·97	29·66	29·29	35·26	35·01		26·90	27·25	30·91			25·87	30·01	1·14	Significant	3·42

Conclusions.—1934-35—POJ 2878 sig. > all the varieties
1935-36—Co 353 > Co 360 > Co 356 > Co 352 > POJ 2878 > Co 407, Co 408 > others
1936-37—(1) Co 360, Co 421, Co 408, Co 356, Co 411 sig. > POJ 2878 (2) Co 356 sig. > Co 353 = Co 352 (3) Co 360 = Co 421 sig. > Co 356, Co 353, Co 352, Co 411, Co 407 (4) Co 408 sig. > Co 407, Co 411

Developmental records

Germination.—At three weeks only POJ 2878 is found to give early and high germination compared to the other varieties. At eight weeks, most of the varieties reach the level of germination as in POJ 2878 except Co 353, Co 356 and Co 360 (Table XVIII).

Borer attack.—The severity of borer attack was much less in 1936-37 than in 1935-36. Excepting Co 360, all the varieties have practically the same percentage of borer attack as POJ 2878.

Tillering.—Periodical changes in tillering at four different periods from germination till harvest for two years is averaged in Table XVII

TABLE XVII

Total shoot counts

(Average of three replicates)

(Area of plot=0·75 gts.)

Variety	At 8 weeks	Before earthing	After earthing	Percentage of success on before earthing-up count	At harvest	Percentage of success on before earthing-up	Remarks
Co 352	575	1971	1067	54·1	885	44·9	Buds planted 750 ; equivalent to 40,000 beds per acre
Co 353	412	1339	891	66·5	837	62·5	
Co. 356	430	1590	879	55·3	740	46·5	
Co 407	590	1801	881	48·9	761	42·3	
Co 408	514	1943	867	44·6	779	40·1	
Co 411	534	1885	880	46·7	689	36·5	
POJ 2878	568	1147	749	65·3	626	54·6	
Co 360	437	935	734	78·5	620	66·3	

The data in Table XVII, when reduced to the number of shoots obtained at different periods and millable canes at harvest for 100 planted buds (Table XVIII), clearly shows the high, medium and low tillering in different varieties ; the data regarding the percentage of germination and borer attack are also given in Table XVIII.

Habit.—The varieties Co 356, Co 360, Co 411 and POJ 2878 have almost erect habit of growth ; the varieties Co 352, Co 353, Co 407 and Co 408 have sub-erect habit and these also tend to lodge. With very vigorous growth the varieties Co 360 and Co 356 also tend to lodge.

TABLE XVIII

Percentage of germination, borer attack and ratio of number of shoots on 100 planted buds

Variety	At 8 weeks	Borrer attack per cent	Before earthing	After earthing	At harvest
Co 352	76·7	7·6	262·8	142·3	118·0
Co 353	55·0	5·7	178·5	118·8	111·6
Co 356	57·4	6·4	212·0	117·2	98·7
Co 407	78·7	5·8	240·1	117·5	101·5
Co 408	69·0	6·5	259·1	115·6	103·9
Co 411	71·2	8·0	251·3	117·3	91·87
POJ 2878	75·8	6·1	152·9	99·9	83·5
Co 360	58·2	9·5	124·7	97·9	82·7

From Table XVIII the varieties could be classified as in Table XIX.

TABLE XIX

Tillering	Varieties
High	Co 352, Co 353
Medium	Co 356, Co 407, Co 408
Low	POJ 2878, Co 360, Co 411

The percentage of flowering canes in the different varieties as recorded on 23 December 1935 was as in Table XX.

TABLE XX

Flowering data

Variety	Percentage of flowering
Co 352	78·1
Co 353	74·9
Co 356	61·1
Co 407	63·2
Co 408	72·2
Co 411	92·3
Co 360	78·6 Fluctuating
POJ 2878	91·7

March of ripeness.—In this trial, the chief consideration being earliness, it was watched from tenth month onwards in the case of Co selections and ninth month in the case of sugarcane-sorghum hybrids; brix and purity tests were taken monthly in the case of Co selections and at twenty days' interval in the case of sugarcane-sorghum hybrids ; these are presented in Tables XXI-XXIII.

TABLE XXI

Brix and purity, 1934-35

Variety	Brix (at No. of days from planting)			
	*270	300	330	
			Brix	Purity
Co 407	16·80	18·87	18·11	90·78
Co 408	14·51	16·63	20·61	90·76
Co 411	14·73	19·00	19·84	90·14
Co 413	15·91	17·97	19·11	90·57
HM 606	11·81	13·72	15·21	80·74
POJ 2878	..	18·01	20·73	92·21

TABLE XXI—*contd.*

Variety	Brix (at No. of days from planting)					
	*240	260	280	300	320	
					Brix	Purity
Co 351	14·69	16·11	17·17	18·10	19·98	86·36
Co 352	13·75	16·31	17·37	18·32	18·24	86·98
Co 353	13·13	15·18	15·57	17·82	17·44	86·76
Co 355	13·75	16·32	16·82	18·12	18·40	85·67
Co 356	12·52	14·10	15·47	17·12	17·16	81·0
Co 357	13·69	15·08	15·72	17·03	16·98	84·09
POJ 2878	13·79	15·43	17·23	18·01	20·47	89·45

*As the polariscope was sent for repairs the readings in early stages could not be recorded.

TABLE XXII

Brix and purity, 1935-36

Variety	Brix (at No. of days from the date of planting)					
	270		300		330	
	Brix	Purity	Brix	Purity	Brix	Purity
Co 407 . .	16·78	82·73	19·52	86·50	22·25	89·39
Co 408 . .	15·11	81·27	17·80	86·52	20·37	89·69
Co 411 . .	16·53	80·34	19·70	88·45	20·60	80·08
POJ 2878 .	15·36	76·83	19·24	86·96	20·06	90·14
Co 360 .	17·23	85·23	18·72	88·51	20·65	90·24

TABLE XXII—*contd.*

Variety	Brix (at No. of days from the date of planting)									
	240		260		280		300		320	
	Brix	Purity	Brix	Purity	Brix	Purity	Brix	Purity	Brix	Purity
Co 351 . .	15·54	79·21	17·48	84·01	19·14	86·70	20·29	89·10	21·29	90·42
Co 352 . .	16·22	81·94	17·53	88·61	19·59	86·65	20·73	92·17	21·07	90·69
Co 353 . .	15·02	79·64	16·85	85·69	17·98	88·63	17·96	89·99	19·37	89·74
Co 355 . .	14·91	81·47	17·09	85·65	17·59	87·44	18·47	89·02	19·47	88·16
Co 356 . .	12·86	72·07	13·98	74·66	14·72	78·05	15·57	80·98	17·41	81·39
Co 357 . .	14·74	80·30	16·07	83·24	16·93	85·65	17·54	87·74	18·98	87·70
POJ 2878 . .	14·68	75·25	15·45	77·20	17·82	84·29	19·24	86·96	20·60	88·29
Co 360 . .	13·87	76·33	15·67	82·90	17·13	85·43	18·72	88·51	20·15	89·16

TABLE XXIII

Brix and purity, 1936-37

Variety	Brix (at days from planting)					
	270		300		330	
	Brix	Purity	Brix	Purity	Brix	Purity
Co 407 . .	17·33	79·77	21·43	88·86	21·99	88·20
Co 408 . .	15·88	79·60	17·08	85·69	18·99	86·56
Co 411 . .	19·42	86·68	20·78	90·90	20·88	89·82
Co 421 .	18·97	82·98	21·72	89·50	22·49	90·16
POJ 2878 .	16·72	78·27	19·58	86·12	20·10	87·36
Co 360 . .	17·29	82·77	19·52	89·35	21·33	90·67

TABLE XXIII—*contd.*

Variety	Brix (at days from planting)									
	240		260		280		300		320	
	Brix	Purity	Brix	Purity	Brix	Purity	Brix	Purity	Brix	Purity
Co 352	15·90	81·87	19·17	89·62	19·96	90·36	21·27	91·26	21·74	91·49
Co 353	14·48	79·69	16·84	84·01	18·18	88·33	19·85	89·71	20·78	91·24
Co 356	12·19	66·71	15·37	79·23	15·87	80·32	18·67	85·67	20·28	86·48
POJ 2878	10·82	59·53	15·82	77·49	17·62	80·87	19·58	86·12	21·21	88·90
Co 360	14·31	77·02	16·36	81·55	17·82	84·74	19·52	89·35	20·44	90·33

The period at which ripeness commences in different varieties, the data regarding the average weight per cane and sucrose and fibre-content in cane are summarised in Table XXIV.

TABLE XXIV

Variety	Period when ripeness commences (in months)	In cane at maximum maturity		Average weight per cane lb.
		Sucrose per cent	Fibre per cent	
Co 352	9¼ to 10	15·55	15·50	1·55
Co 353	9½ to 10	13·94	16·79	1·69
Co 356	10 to 10½	13·52	18·67	2·05
Co 407	10	16·35	16·45	1·78
Co 408	11 to 11½	15·72	15·34	1·89
Co 411	10	15·29	13·81	1·94
Co 360	10 to 10½	16·84	14·04	2·54
POJ 2878 . . .	10 to 10½	16·63	14·42	2·14

The varieties Co 360 and Co 407 are almost equal in sucrose-content to POJ 2878, and Co 407 is comparatively more fibrous; the sugarcane-sorghum hybrids are higher in fibre-content compared to the varieties Co 360 and POJ 2878.

Relative yield performance with control varieties

The comparative value of the Co varieties and sugarcane-sorghum hybrids from standpoint of tonnage, average of three years, taking POJ 2878 and Co 360 as 100 is presented in Table XXV.

TABLE XXV

Relative yield performance of varieties

Variety	Cane in tons per acre (average of three years	Comparative value of different varieties from standpoint of cane-taking	
		Co 360 as 100	POJ 2878 as 100
Co 352	31·04	90·44	105·4
Co 353	30·13	87·48	102·0
Co 356	32·71	95·28	111·1
Co 407	28·49	83·01	96·77
Co 408	31·95	93·09	108·5
Co 411	28·68	83·56	97·4
Co 360	34·36	100·00	116·6
POJ 2878	29·45	85·78	100·0

Conclusions.—In this shallower type of soil, the varieties Co 360, Co 356, Co 408, Co 352 and Co 353 have yielded as much as POJ 2878 but slightly less than Co 360. The variety Co 360 has as much sucrose per cent in cane as POJ 2878 and the varieties Co 407, Co 408 and Co 352 are the next best. The cane-sorghum hybrids do not show maturity earlier than 9½ months and the control varieties Co 360 and POJ 2878 show trend towards maturity from tenth month onwards. The cane-sorghum hybrids are comparatively more fibrous than the control varieties.

EXPERIMENT IV

October-planting trials, 1934-35 to 1936-37

Investigations in the performance of Coimbatore selections described previously have definitely shown that under Padegaon conditions all the promising varieties start flowering from October to December, and with this the growth closes. This is found to result in low yields specially in the early-flowering varieties. It was, therefore, proposed to see what advantage could be gained by planting these varieties in October as it was considered that by this early planting the crop would get additional two to three months for its growth. With this view the trials were commenced with the promising selections from October 1934, the method being exactly similar as in the trials previously described but with only a smaller plot size. The manurial dose was increased to 225 lb. nitrogen from the usual 150 lb. for January planting.



Co 407 Co 408 Co 413 Co 419 Co 290 POJ 2878 EK 28

October planting : age of crop 14½ months

These trials were conducted for three years. As some of the varieties were discontinued from the second year, the results are represented year by year. The varieties POJ 2878 and EK 28 were grown as control during this three-year period.

Year 1934-35.—During this period, thirteen varieties, together with two control varieties were under trial.

Co 413 and Co 419 have yielded significantly better than the control varieties. Co 290 and Co 407 have equalled POJ 2878. Co 360, Co 364, Co 400, Co 408, Co. 410, Co 411 and Co 414 are significantly better than EK 28.

Year 1935-36 and 1936-37.—During these two years the varieties Co 364, Co 400, Co 404, Co 410, Co 411 and Co 412 were omitted and the remaining were continued.

In 1935-36, Co 419 and Co 413 are significant over POJ 2878. All the remaining varieties are significantly better than EK 28.

In 1936-37, the varieties Co 419, Co 290, Co 413, Co 408, Co 414 are significantly better than POJ 2878 ; the varieties Co 360 and Co 407 show better than POJ 2878.

The three years' data of cane and commercial cane sugar per acre are presented in Table XXVI year by year.

Some of these varieties are illustrated in Plate XXXII.

Developmental records

Germination.—Unlike the January planting, very high germination is secured at three weeks in this planting. Maximum germination occurs at six weeks. The varieties Co 419, Co 413 and Co 407 have come out the best. (Table XXVIII).

Borer attack.—The incidence of borer attack is the least in this planting compared to the January planting.

Periodical changes in tillering.—Periodical changes in tillering (average of two years) are presented in Table XXVII.

The data in Table XXVII, when reduced to number of shoots obtained at different periods and millable canes at harvest for 100 planted buds (Table XXVIII), clearly show the high, medium and low tillering in different varieties ; data regarding percentage of germination and borer attack are also given in Table XXVIII.

On the basis of the data in Table XXVIII the varieties can be classified as shown in Table XXIX.

It is interesting to observe, that in this planting the ratio of millable canes at harvest is uniformly higher in all the varieties compared to January planting (Tables IV and XI).

Habit.—The varieties Co 290, Co 360, Co 413, Co 419, E K 28 and POJ 2878 have almost erect habit of growth ; the varieties Co 407, Co 408 and Co 414 have sub-erect to slanting habit. The varieties Co 419 and Co 360 tend to lodge in varying degrees at harvest time.

The percentage of flowering canes in different varieties as recorded on 21 November 1937 was as shown in Table XXX.

March of ripeness.—The year-by-year data for brix and purity is presented in Table XXXI.

TABLE XXVI

Yields of millable canes and commercial cane sugar in tons per acre
(Data for three years)

	Co 290	Co 360	Co 407	Co 408	Co 413	Co 414	Co 419	POJ 2878	E K 28	Co 364	Co 400	Co 404	Co 410	Co 411	Co 412	General mean	S. E. of treatment mean	Significance by z-test $P=0\cdot05$	Critical difference for significance
1934-35																			
Cane	46·91	42·92	45·47	42·70	53·76	41·27	62·59	45·11	31·94	44·04	45·04	41·65	41·72	43·17	38·08	44·42	2·89	Significant	7·97
C. C. S.	5·84	6·17	6·18	5·74	7·17	5·93	7·09	6·42	4·36	5·50	4·29	5·10	5·60	5·63	4·76	Not calculated statistically			
1935-36																			
Cane	50·44	46·93	50·66	50·48	54·64	52·02	68·57	47·69	35·80	...	...	...	...	...	...	50·8	2·47	Significant	7·22
C. C. S.	6·14	5·46	6·83	6·89	6·93	7·29	8·55	6·90	4·89	...	...	...	...	...	...	Not calculated statistically			
1936-37																			
Cane	52·056	47·41	46·41	54·16	58·26	53·88	70·04	39·83	30·21	...	...	...	...	...	...	51·37	2·90	Significant	8·47
C. C. S.	9·31	6·43	6·35	7·06	7·93	7·63	9·72	5·65	4·21	...	...	...	...	...	...	Not calculated statistically			

Conclusions:—1934-35.—Co 419, Co 413 sig. > POJ 2878

1935-36.—Co 419 sig. < POJ 2878 ; Co 413 almost sig. > POJ 2878 ; Co 413, Co 414, Co 407 = Co 408 = Co 290 > POJ 2878 = Co 360 sig. > EK 28

1936-37.—Co 419, Co 290, Co 413, Co 408, Co 414 sig. > POJ 2878 ; POJ 2878 sig. > EK 28

TABLE XXVII

Total shoot counts

(Average of four replicates)

(Area of plot 0·33 gts.)

Variety	At 6 weeks	Before earthing	After earthing	Percentage of success on before earthing-up count	At harvest	Percentage of success on before earthing-up count	
Co 419	199	577	429	74·3	393	68·1	Buds planted=250 (equivalent to 30,000 buds per acre)
Co 413	200	814	529	65·0	402	49·4	
Co 290	179	714	516	72·3	457	64·0	
Co 407	192	565	438	77·5	410	72·6	
Co 408	176	502	397	79·1	368	73·3	
Co 360	171	387	364	94·1	349	90·2	
Co 414	183	539	380	70·5	316	58·6	
POJ 2878	179	498	352	70·7	317	63·7	
EK 28	164	314	256	81·5	230	73·2	

TABLE XXVIII

Percentage of germination, borer attack and ratio of number of shoots on 100 planted buds

Variety	At 6 weeks	Borer attack per cent	Before earthing	After earthing	At harvest
Co 419	79·9	1·1	230·8	171·6	157·2
Co 413	80·1	1·0	325·6	211·6	160·8
Co 290	71·6	0·7	285·6	206·4	182·8
Co 407	77·0	1·0	226·0	175·2	164·0
Co 408	67·9	1·6	200·8	158·8	147·2
Co 360	68·1	2·0	154·8	145·6	139·6
Co 414	73·4	1·8	215·6	152·0	126·4
POJ 2878	71·7	0·8	199·2	140·8	126·8
E K 28	65·7	2·0	125·6	102·4	92·0

TABLE XXIX

Tillering	Varieties
High	Co 290
Medium	Co 413, Co 419, Co 407, Co 408
Low	Co 360, Co 414, POJ 2878
Very low	EK 28

TABLE XXX

Flowering data (October planting)

Variety	Percentage of flowering
Co 290 . .	72·7
Co 360 . .	10·6
Co 407 . .	64·9
Co 408 . .	50·3
Co 413 . .	56·4
Co 414 . .	41·0
Co 419 . .	76·7
POJ 2878 .	80·8
EK 28 . .	20·9

On account of the long interval over which the crop is standing, and also practically the same time of flowering, its tendency to being early, mid-late or late is not clearly visible in the different varieties. Yet the varieties, Co 407, Co 408, Co 360, POJ 2878 could be started for crushing from November and the remaining in December.

The average weight per cane and percentage of fibre and sucrose in cane in the different varieties is given in Table XXXII.

The varieties Co 414 and POJ 2878 show same sucrose-content and the remaining varieties, except Co 360, follow next. Most of the va ieties were found to record very steady weight per cane from year to year.

Relative yield performance.—The comparative value of the Co varieties from standpoint of cane and commercial cane sugar, with POJ 2878 and EK 28 as 100, average of three years, is presented in Table XXXIII.

Conclusions.—The variety Co 419 has outyielded all the varieties including the controls. The varieties Co 413, Co 290, Co 414 and Co 408 have given slightly higher tonnage than POJ 2878 but from sugar point of view these are almost equ valents or slightly better than POJ 2878. There is not much differentiation in the ripening of the different varieties owing to the pre-seasonal time of planting and most of the varieties show ripenes at 13½ to 14½ months' age of the crop. It is interesting to observe that most of the varieties except Co 419, Co 413 and Co 290 show practically the same sugar recovery as

TABLE XXXI

Brix and purity data

Serial No.	Variety	October			November			December			January			February			March		
		1935	1936	1937	1935	1936	1937	1935	1936	1937	1935	1936	1937	1935	1936	1937	1935	1936	1937
								Brix											
1	Co 419 .	14·13	17·46	17·9	17·74	19·99	19·51	21·12	20·40	21·77	...	22·63	22·67	...	20·60	13·5	...	16·65	21·30
2	Co 413 .	16·01	17·84	18·37	18·79	20·29	20·09	21·07	19·91	20·31	...	21·78	22·53	...	21·35	22·68	...	18·73	20·62
3	Co 290 .	16·28	18·84	18·44	18·82	20·06	19·72	20·15	20·94	21·42	...	21·50	21·02	...	21·04	21·60	...	19·80	18·88
4	Co 407 .	15·16	18·96	18·88	19·14	21·62	21·79	21·84	22·85	23·22	...	23·16	21·01	...	22·12	22·47	...	20·03	18·58
5	Co 408 .	16·78	18·38	17·62	18·56	21·29	19·79	21·02	22·09	21·03	...	22·43	22·31	...	22·22	22·83	...	19·20	21·43
6	Co 360 .	15·50	20·49	19·82	15·90	21·52	20·11	21·22	19·67	20·61	...	22·13	22·20	...	21·29	21·22	...	18·86	19·28
7	Co 414 .	17·06	19·99	20·04	19·44	21·85	20·64	21·61	22·55	22·16	...	22·05	22·49	...	18·94	20·31	...	14·76	15·82
8	POJ 2878	16·42	20·22	20·55	19·28	23·39	22·61	21·79	22·56	23·09	...	23·46	23·73	...	22·22	22·56	...	19·12	19·02
9	EK 28 .	17·08	18·95	20·94	18·47	20·17	21·44	20·90	20·86	21·43	...	21·63	22·96	...	21·88	24·8	...	19·23	21·73
								Purity											
1	Co 419 .	75·60	83·81	83·41	83·99	89·78	88·10	89·32	87·26	90·07	...	89·74	89·84	...	90·57	91·45	...	86·24	90·99
2	Co 413 .	82·64	86·76	88·90	86·48	90·59	91·37	91·85	90·82	91·16	...	90·99	91·47	...	90·55	92·47	...	88·47	91·77
3	Co 290 .	80·97	87·84	85·43	85·47	89·30	86·92	87·70	86·64	88·90	...	89·50	88·45	...	88·84	88·45	...	88·26	86·20
4	Co 407 .	75·34	85·96	85·88	82·94	90·40	89·62	90·59	89·66	90·42	...	89·0	88·24	...	90·44	89·13	...	87·38	86·86
5	Co 408 .	83·83	88·74	88·76	86·80	91·94	90·65	92·41	90·01	90·67	...	90·67	91·70	...	91·22	90·72	...	87·82	90·80
6	Co 360 .	79·49	89·95	90·67	80·50	91·43	90·31	92·37	86·90	91·70	...	90·67	84·35	...	88·47	85·02	...	83·56	78·16
7	Co 414 .	82·30	87·36	87·98	36·38	90·84	91·03	92·30	88·92	90·40	...	90·44	89·48	...	89·73	88·14	...	81·04	82·45
8	POJ 2878	78·75	88·67	89·33	86·88	91·37	91·39	92·26	91·37	91·94	...	92·47	92·43	...	91·91	92·47	...	89·13	87·44
9	EK 28 .	83·62	86·44	90·61	84·80	89·50	91·28	92·06	90·82	91·52	...	90·55	91·70	...	90·86	92·45	...	85·96	90·93

POJ 2878. EK 28 has proved a complete failure in this trial. Unlike other plantings most of the varieties in this planting give higher number of millable canes at harvest and the intensity of borer attack is the least.

TABLE XXXII

Chemical composition and average weight per cane

	Co 419	Co 413	Co 296	Co 407	Co 408	Co 360	Co 414	POJ 2878	EK 28
Average weight per cane (lb.)	3·28	2·62	2·29	2·21	2·65	2·53	3·13	2·57	2·67
Fibre per cent in cane .	12·39	13·87	14·18	18·41	15·24	13·28	13·03	15·87	12·51
Sucrose per cent in cane .	15·55	15·28	15·19	15·46	15·50	14·18	16·55	16·48	15·79

TABLE XXXIII

Cane and commercial cane sugar in tons per acre

(Three years' average)

	Co 419	Co 413	Co 290	Co 407	Co 408	Co 360	Co 414	POJ 2878	EK 28
Cane tons per acre	67·07	55·55	53·13	47·51	49·11	45·75	49·06	44·21	32·65
Percentage on POJ 2878	151·7	151·7	120·1	107·5	111·1	103·5	111·0	100·0	73·86
Percentage on EK 28	205·4	170·1	162·8	145·5	150·4	140·2	150·3	135·4	100·0
C. C. S. tons per acre	8·45	7·34	7·10	6·45	6·56	6·02	6·95	6·32	4·49
Percentage on POJ 2878	133·8	116·1	112·4	102·1	103·8	95·26	110·0	100·0	71·04
Percentage on EK 28	188·2	163·5	158·1	143·6	146·1	134·1	154·8	140·8	100·0

SUMMARY AND CONCLUSION

Cane selections together with sugarcane-sorghum hybrids numbering in all seventy-nine, from Coimbatore, Hebbal-Mysore and Manjri were under trial, from which promising selections were grouped and tried for three years as January-planted crop. They were also under trial as October-planted crop. All the trials were on replicated system and the data analysed as per Fisherian method. The results have been expressed in cane-weight, *gul* and commercial cane sugar together with the maturity period of each variety and its general behaviour as regards habit, incidence of pests, etc.

(1) As January-planted crop, the varieties Co 419, Co 413 and HM 320 have proved their superiority over the control varieties POJ 2878, EK 28 and Pundia. When both the groups are considered together Co 290 and Co 360 have not only come up to the level of POJ 2878 but are superior to EK 28 and Pundia in cane-weight, *gul* and commercial cane sugar. As regards maturity, Co 419 ripened within 12¾ months, HM 320 within 13 to 13½ months. From the point of keeping quality it is observed that Co 419, Co 413, Co 360 and Co 290 could keep up juice quality till March, whilst

HM 320, a late-maturing cane, keeps even longer. In the developmental behaviour of the crop the important points are germination, tillering, lodging, ease of trashing, and good root-system. From all these aspects Co 419, Co 413 and Co 290 are the best. Co 360 has a peculiar root-system, which is conducive to rapid growth but being defective induces lodging. It is not also self-stripping, and is, therefore, susceptible to mealy bugs. However, it has shown a good performance as late-planted crop even though it is a flowering variety. HM 320 has also a lodging tendency and is further poor in sucrose as Pundia. Thus, Co 419, Co 413, Co 290 and even Co 360 can be good factory canes and HM 320 a cultivator's cane.

(2) As regards early cane selections and sugarcane-sorghum hybrids, planted in January, Co 407 and Co 411 have proved to be eleven months' cane whilst sugarcane-sorghum hybrids have not shown start in maturity before 9½ months which has falsified the expectation of its reaching maturity in six months. Although the yield is not the main factor for drawing conclusion in the case of these varieties no marked superiority is observable of early varieties as well as sugarcane-sorghum hybrids over POJ 2878.

(3) As regards October-planting, varieties Co 419, Co 413, Co 290, Co 407, Co 408 and Co 414 have shown their superiority over the control varieties POJ 2878 and EK 28 ; Co 360 is a mediocre cane in cane-weight and also in commercial cane sugar. It would further be seen that the benefit of additional three months for flowering varieties has resulted in highly increased number of canes at harvest which fully go to increase the yield significantly in the end.

Acknowledgements

The cane varieties referred to in the different experiments in this paper were received from Rao Bahadur T. S. Venkatraman and Mr. N. L. Dutt of the Imperial Sugarcane Breeding Station, Coimbatore and Dr V. K. Badami, Mysore. To all of them the authors' thanks are due.

The authors also acknowledge with best thanks the valuable suggestions and criticisms they have received in the presentation of these data from Dr R. D. Rege and Dr J. K. Basu of the Sugarcane Research Scheme, Bombay-Deccan, Padegaon.

REFERENCES

Basu, J. K. and Sirur, S. S. (1938). *Ind. J. Agric. Sci.* **8**, 637-98
Knight, J. B. (1925). *Bombay Dept. Agric. Bull.* No. **122**
Patil, P. C. and Patwardhan, N. B. (1925). *Bombay Dept. Agric. Bull.* No. **125**
Rege, R. D. and Wagle, P. V. (1939). *Ind. J. Agric. Sci.* **9**, 423-48

EMBRYO OF THE INDIAN MANGOES (*MANGIFERA INDICA* LINN.)

BY

P. K. SEN

AND

P. C. MALLIK

Fruit Research Station, Sabour, Bihar

(Received for publication on 5 February 1940)

(With Plates XXXIII and XXXIV and three text-figures)

IN the studies on mango at Sabour, the embryo has received attention from two aspects. Firstly, it is known that large amount of carbohydrates are utilised in developing the fruits but the embryos in the seeds require more nitrogen than carbohydrate for their growth and development, whereas fruit-bud formation is believed to be dependant on a high carbohydrate-nitrogen ratio. A knowledge of the relative times of growth and development of the fruit, seed and embryo as also that of the fruit-bud differentiation in mango would, therefore, be of interest in connection with the problem of alternate bearing in this fruit. Secondly, it seems important that it is necessary to have a knowledge of the behaviour of the embryo because of the possibilities of improving the present varieties by hybridization, and also if it may be possible to use the apogamically produced seedlings in the polyembryonic strains as clonal root-stocks.

THE RELATIVE TIMES OF GROWTH AND DEVELOPMENT OF THE FRUIT, SEED AND EMBRYO

As far as the writers are aware, no study on this aspect of the mango has yet been made, although it has received attention in a number of other fruits; thus Connors [1919], Blake [1925], Lilleland [1931; 1934], Tukey [1933; 1934] and others working on peach, plum, apricot and cherry have shown that development of stone-fruit passes through three well-marked stages: (1) Rapid growth after fertilization due mainly to increase in size of stone. The nucellas and integuments grow rapidly to full size, but the embryo does not start active growth until near the end of this period. (2) A period during which the growth of fruit is retarded but the stone hardens and the embryo rapidly reaches full development. (3) Renewed rapid development of the fruit to maturity. Sen [1937] found a similar phenomenon in apple. The work described below was taken up with a view to gathering the information in mango.

A sample number of fruits was collected every week from the time of fruit set-up to the time of fruit-maturity in the Bombai, Langra and Fazli mangoes and the volume, and maximum length, breadth and thickness of the fruit, seed and embryo, and only the lengths of the radicle and plumule separately, were determined. During the first two to three weeks when the fruits

were yet within one cm. in length, a sample consisted of 50-100 fruits, then until they were within about 2·5 cm., a sample consisted of twenty-five fruits, thereafter ten fruits were collected per week, from three comparable trees (sixteen year old in 1938) under each variety.

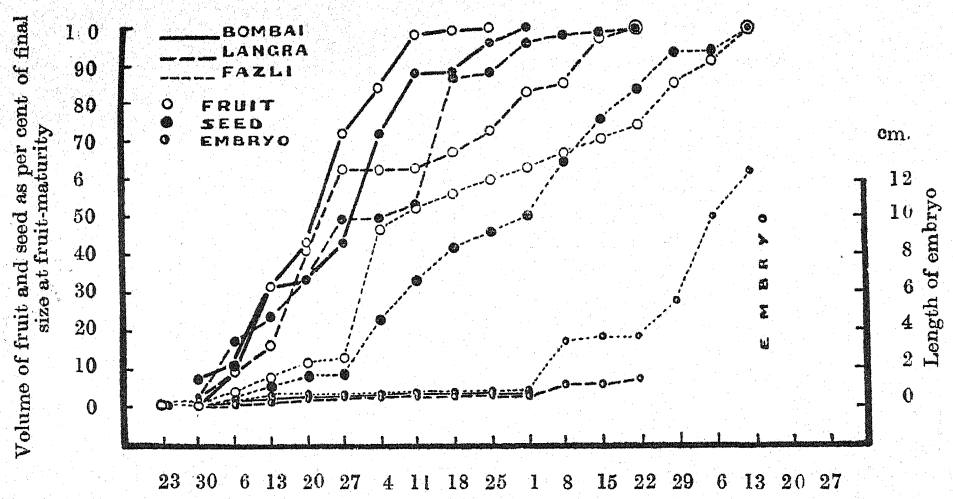


FIG. 1. Increases in volume of the fruit and seed expressed as percentage of the final size, at fruit-maturity and that in length of th · radicle and plumule (marked as embryo) in 1938

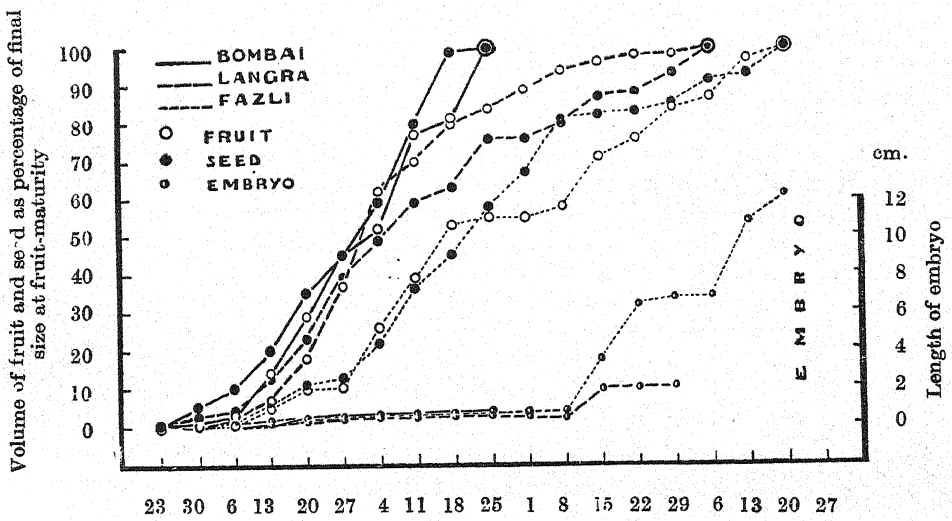


FIG. 2. Increases in volume of the fruit and seed expressed as percentage of the final size, at fruit-maturity and that in length of the radicle and plumule (marked as embryo) in 1939

The study was first made in 1938 and then repeated in 1939. The increases in volume of the fruit and seed, expressed as percentage of the final size, at fruit-maturity, and that in length of the radicle and plumule, in the three varieties, are graphically shown in Figs. 1 and 2; and only the relevant data are given in the appendix (Tables A and B).

The Bombai is an early variety ripening towards the end of May or beginning of June ; Langra, a mid-season variety ripening towards the end of June ; and Fazli, a late variety ripening after the middle of July.

As will appear from Figs. 1 and 2, unlike the temperate fruits mentioned above, fruit and seed in the mango develop concurrently. The earlier the fruit ripens the more rapid is its rate of development. From the appendix (Tables A and B) it will be seen that the cotyledons in the mango also grow along with the seed, the rate of growth of the radicle and plumule, however, remains very slow until the beginning of June irrespective of the varieties and their times of fruit-maturity. In the case of Bombai where the fruit had reached full maturity by the end of May, the radicle and plumule showed little change in the rate of growth ; in the other two cases, however, the radicle and plumule showed a sudden rise in their rate of growth after the first week of June. Although the fruits of Langra and Fazli reached maturity at different times, their embryos showed this sudden increase at the same time, in both the years. After this sudden rise the rate of increase in both the varieties showed a flattening out again. The Langra variety maintained this retarded rate of growth till its fruit matured, but in the case of Fazli there was another abrupt rise towards the end of June in 1938, and after the first week in July in 1939 when in there respective years the Langra fruit had already ripened. This renewed rapid rate of increase continued till fruit-maturity, resulting in a phenomenon like vivipary, the plumules and radicles quite often reaching in some cases a length of 20 to 25 cm. An observation of this phenomenon in a ripe fruit of the Fazli mango was previously recorded by Nandi [1934].

Whether or not the sudden increases in the rate of gro th of the plumule and radicle observed in the cases of Langra and Fazli are due to seasonal influence, in some way related to the nutritional conditions of the tree, the writers have no sufficient data at the present moment to come to any conclusion. The one characteristic of the mango that its seed cannot be stored, at any rate, under the ordinary conditions, and that for successful germination, the stone should be sown soon after it is removed from the ripe fruit, should also be borne in mind in this connection. The suggestion put forward by Nandi [1934] that this phenomenon in Fazli might be due to unfavourable condition of the soil seems rather remote as it appears to be a normal feature of this variety, and as the varieties like Bombai and Langra grown on the same soils do not show this phenomenon.

Behaviour of the embryo

As to this second question, points of fundamental interest have arisen since it has been found that although pollination and fertilization is necessary for the development of the fruit, the zygote in mango does not always produce an embryo. It may degenerate and take no part at all in the production of any embryo in the seed. On the other hand adventive embryos of nucellar origin may arise.

The behaviour of the embryo in mango fruit first attracted attention because of the occurrence, in many cases, of more than one sprout from its seeds. According to Arndt [1935] Schacht recorded the presence of polyembryony in mango in 1859 ; Strasburger [1878] and Cook [1907] concluded that

the extra embryos were of nucellar origin, but the latter failed to ascertain whether or not the 'strong' embryo came from the fertilised megagamete. He noted as many as eight embryos arising from a single seed. Mendiola [1926] reported that ten or even thirty seedlings may grow from a single seed (Carabao or Pico variety).

Working on polyembryonic varieties, Belling [1908] in the Florida No. 11 mango and Juliano [1934] in the Strawberry mango have found that in these two cases the zygote totally fails to develop and all the embryos in a seed are nucellar in origin. Juliano and Cuevas [1932] and Juliano [1937], in the Pico and Carabao mangoes respectively, have shown that the zygote usually persists and forms a sexual embryo, but it may degenerate and take no active part in the production of any embryo in the seed. The adventive embryos in the seed are nucellar in origin. Juliano [1937] also concludes that in the cases of polyembryonic seeds where both sexual and asexual embryos are produced it has not been possible to ascertain, after the seedlings have sprouted, which of them came from the fertilised megagamete; further, where only one sprout arises from a seed on germination, this seedling may have been produced either asexually or sexually.

Juliano opines that the Pico and Carabao mangoes are probably on their way to sterilization and degeneration in their zygotes so that in course of time they will also produce apogamic embryos only, and progenies true to type may be grown by seedage, as is the case now in Florida No. 11 and Strawberry mangoes.

The use of such mangoes as develop apogamic embryos only should, therefore, provide a sure method of supplying root-stocks that will produce uniform trees. On the other hand the zygote degeneration in mango is a serious handicap in hybridization work, as the varieties showing this phenomenon cannot be used as a female parent.

Although by far the largest number of our Indian mangoes are known to be mono-embryonic, i.e. only one seedling arises from one seed, polyembryonic varieties are not unknown. In fact the Strawberry mango on which Juliano has worked is described as an Indian variety. Several varieties of polyembryonic mangoes have been found in the Malabar Coast and the Kodur Fruit Research Station, Madras, has taken up their collection.

Incidentally, a point of fundamental interest noted by Juliano [1937] is that many of the mono-embryonic Indian mangoes when grown in the Philippines and Florida appear to develop polyembryony at least in a greater proportion, if not all, of their seeds when grown there. As to how this comes about, he doubts if it is due to natural cross-pollinations between the polyembryonic mangoes that are the natives of the locality, and the imported Indian varieties, as in that case, he thinks, all the Indian mangoes now growing in those islands should have shown polyembryony. He suggests that if it is a case of reversion due to the influence of environment, and if the progenies of the varieties which show such a phenomenon revert to mono-embryony when planted back in their own home, it may settle once and for all which character, poly or mono-embryony is the more primitive, and this may indicate the possible origin of all the present mangoes.

There again occurs another phenomenon, namely that many of our Indian mangoes, though in very small numbers, give rise to multiple shoots, but only

one tap-root in germination. These shoots arise from the hypocotyl. Arndt [1935] has described this phenomenon in mango in the West Indies. He is inclined to think that the multiple shoots which arise from the seeds may originate through polyembryony, the development of adventitious buds on the seedlings before or during germination, or a combination of the two types.

At our research station at Sabour, Bihar, we have almost every year seen many of the local varieties showing this phenomenon of multiple shoots in germinating seeds. The results of a record taken in 1939 are shown in Table I. In the case of Fazli where the embryo in the seed of a ripe fruit shows fairly advanced growth, instances of multiple plumules are quite commonly seen. A photograph of such a Fazli seed and, in contrast, a seed of an Indian polyembryonic mango, namely, Goa (Kasargod) is shown in Plate XXXIII, fig 1. Drawings of the same Fazli seed are shown in Fig. 3 so as to enable a clear examination of the orientation of the multiple shoots. From the two very distinct cotyledons, one single root and the axillary orientation of the extra shoots it would suggest that the present case is one of adventitious budding. Here the main plumule has actually been suppressed in the centre and some of the axillary ones have outgrown it. Plate XXXIII, fig. 2 (*a* and *b*) show photographs of two germinated seeds of Langra and Bombai respectively, producing multiple shoots. In these cases also, the extra shoots appear to have arisen from the axils of the cotyledons. Plate XXXIII, fig. 2 (*c*) shows a germinated seed of an Indian polyembryonic mango, namely Kurakkan producing three distinct seedlings, one of them further shows a side shoot arising from its hypocotyl.

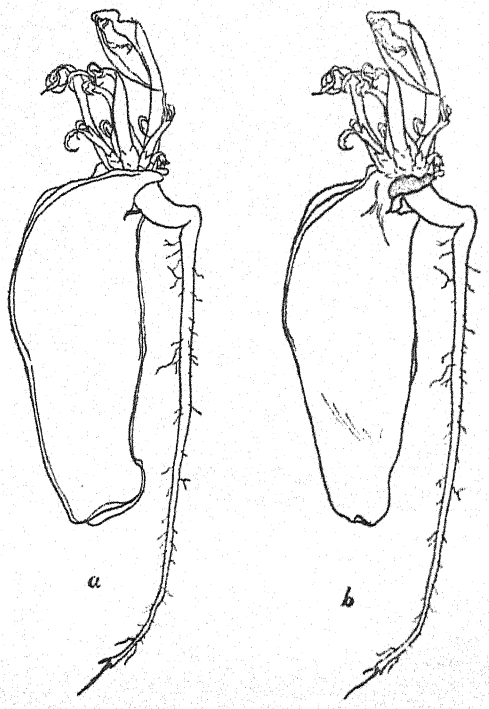


FIG. 3. Drawings of the Fazli seed photographed in Plate XXXIII, fig. 1, (*a*) with both the cotyledons intact, (*b*) after one of the cotyledons has been removed; showing extra shoots arising at the axils of the cotyledons

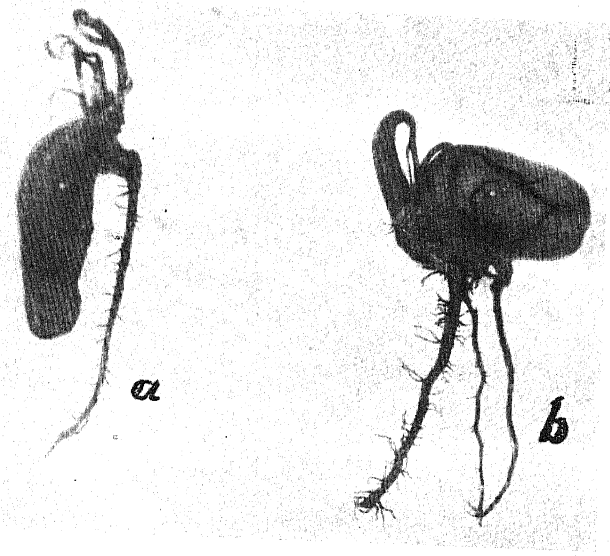


FIG. 1. (*a*) A Fazli seed showing multiple shoots but a single tap-root, (*b*) a polyembryonic seed of the Goa (Kasargod) mango showing three germinating embryos

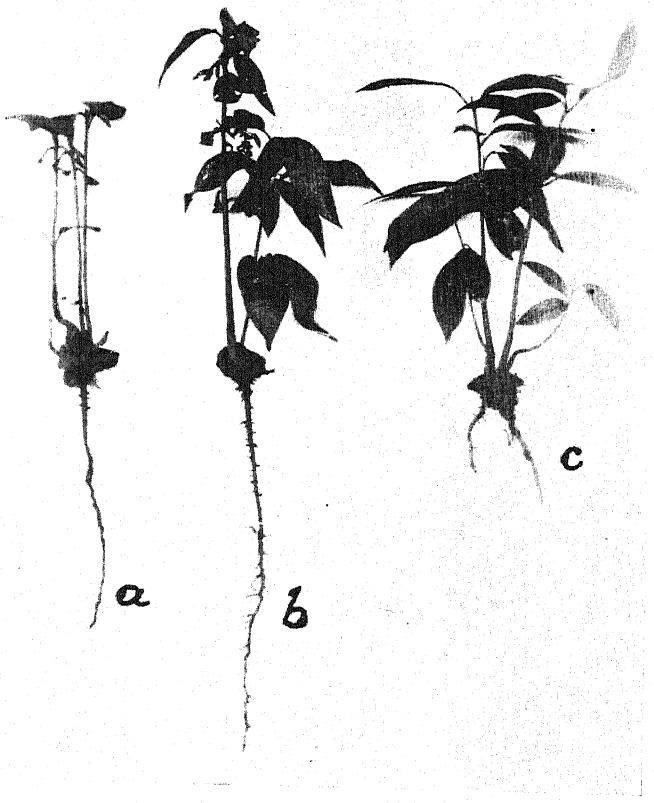
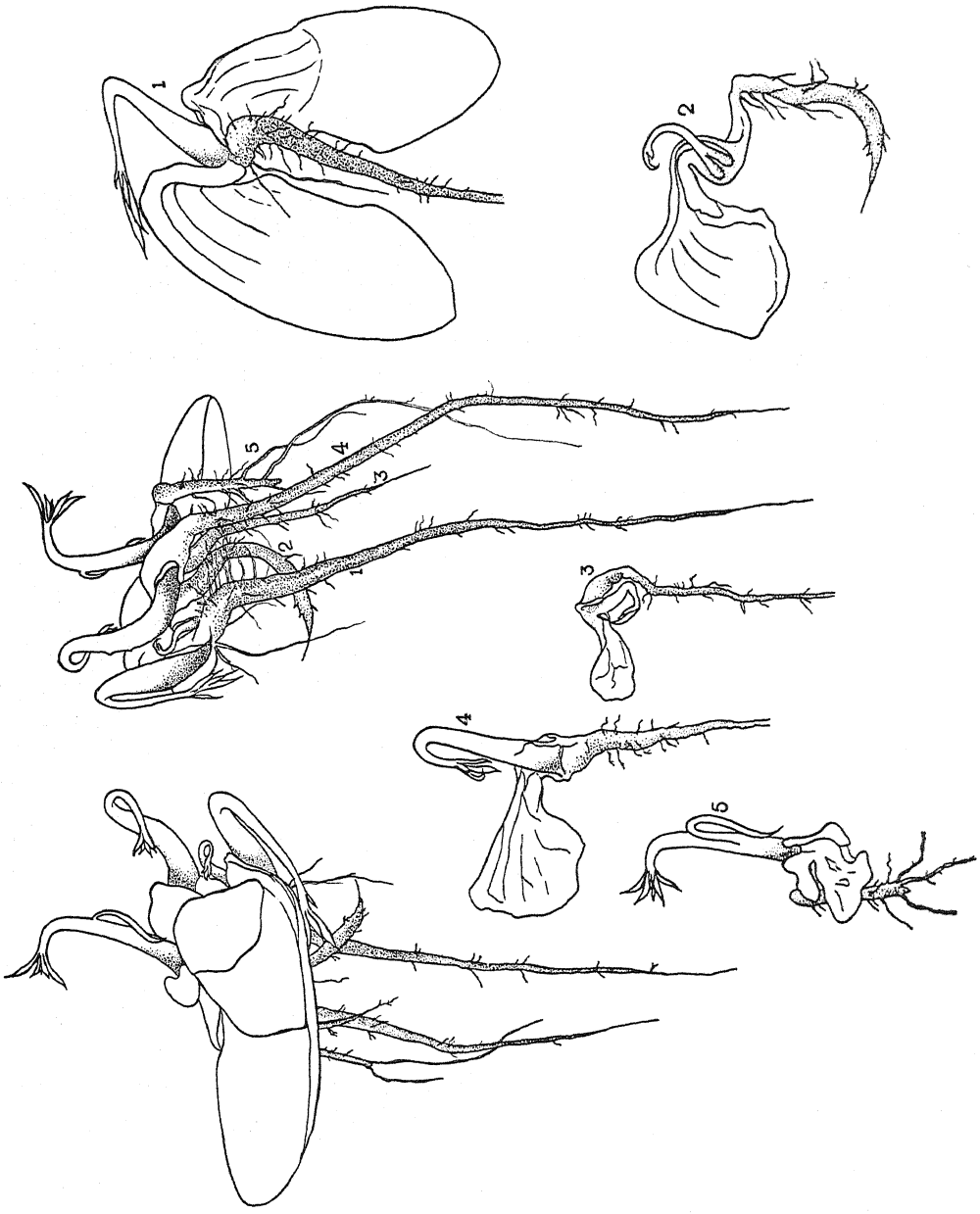


FIG. 2. Germinated seeds : (*a*) Langra, (*b*) Bombai showing multiple shoots, (*c*) a polyembryonic seed (var. Kurakkan) showing three seedlings. The tips of the roots were unfortunately torn in excavation



A germinating polyembryonic seed (var. colour) showing the entire seed in two views and the five embryos 1-5 after separation

TABLE I

Number of shoots arising on germination in three varieties of mango

Seeds from		Number of seeds sown	Number germinated	Number of seeds producing			
				1 shoot	2 shoots	3 shoots	More than 3 shoots
Bombai	Seedling tree	280	208	205	2	1	..
	Grafted tree	280	217	210	3	3	1
Langra	Seedling tree	280	148	136	9	3	..
	Grafted tree	280	207	202	5	..	..
Fazli	Seedling tree	150	36	35	..	1	..
	Grafted tree	150	21	15	4	2	..

From the results shown in Table I, it would appear that the seeds collected from fruits of seedling trees and from grafted trees make little difference in germination ; but among the three varieties Fazli is a very poor germinater. Whether or not this indicates the occurrence of zygote degeneration or embryo abortion in this variety, has not been investigated, but cases of deformity of the embryo have been noticed in large numbers so that while in the varieties such as Bombai and Langra the cotyledons practically fill the cavity of the stone in this variety quite often, insignificant cotyledons with undeveloped radicle and plumule are found to occupy only one corner of the cavity.

In view of the above a knowldge of the behaviour of our polyembryonic as well as the important mono-embryonic varieties of mango seems to be important. In the case of the polyembryonic varieties no doubt it would appear difficult to distinguish the sexually produced seedling from the asexual ones, or the seeds possessing only asexually produced embryos from those which have both the sexual and asexual embryos ; but if it is possible to discover varieties like Florida No. 11 or Strawberry mango that produce all the embryos asexually, we shall be in a position to use them quite easily as root-stocks ensuring uniform trees.

As regards the mono-embryonic varieties, most of our economic mangoes belong to this group. Whether or not these varieties can be improved by hybridization in respect of quality and bearing habit* is yet to be known. For such attempts, a knowledge of the behaviour of their zygotes after fertilization will be of great help. Unfortunately, however, little work on this important aspect of the Indian mangoes has yet been done ; the only report known to the writers is a note on some preliminary observations made by Maheswari [1934].

* Most of the best quality of Indian mangoes are alternate bearers.

With the above in mind, samples of seeds of five varieties of our West Coast polyembryonic mangoes were collected through the courtesy of Mr K. C. Naik, Superintendent of the Kodur Fruit Research Station, Madras, and a preliminary morphological examination, including a germination test, of these was carried out during the last summer. The samples included seventy-five seeds of each of the four varieties, namely Olour, Goa, Goa (Kasargod) and Mylepelian and 500 seeds of Kurakkan, variety. The seeds were gathered, transported to Bihar from Madras and sown within a week in April-May 1939. The first four varieties were sown in seed-beds, and the last in pots at the rate of one seed per pot. After one week of sowing, when the seed had not yet germinated twenty-five seeds of each variety were unearthed for examination. Table II gives the number of embryos occurring in them. All these varieties showed more than one embryo in an overwhelming majority of cases ; in each of the varieties, however, a few cases showing a single embryo, without any trace of polyembryony, were found. Among the 125 seeds examined in the five varieties, the highest number of embryos in a single seed was six, observed only in one case in the Kurakkan variety.

TABLE II

Polyembryony in mango

Variety	Number of stones examined	Number of stones with the following number of embryos					
		1	2	3	4	5	6
Kurakkan	25	5	11	6	2	0	1
Goa (Kasargod)	25	1	8	9	5	2	0
Olour	25	5	6	4	9	1	0
Mylepelian	25	4	8	8	4	1	0
Goa	25	6	15	0	0	0	0*

* Four rotted, no trace inside the stone

Plate XXXIV presents drawings of a germinating seed of the Olour variety. It shows the entire seed in two views and the five embryos after separation. As is found here, all the polyembryonic seeds examined have shown one ' strong ' embryo having two cotyledons almost as big as a normal pair of cotyledons in a mono-embryonic seed. In the case of others, the size of the cotyledons varies according to the position in which it lies in the seed so as to accommodate all the cotyledons of all the embryos within the stone. Embryos 1 to 5 represent this feature.

Table III shows the results of germination in the five polyembryonic varieties. It appears that a considerable number of seeds in all the varieties failed to germinate successfully, also a good many of them finally produced only one seedling.

TABLE III

Number of seedlings arising on germination in five varieties of polyembryonic mango

Seeds from	Number of seeds sown	Number germinated	Number of seeds producing			
			1 seedling	2 seedlings	3 seedlings	More than 3 seedlings
Goa	50	8	5	2	1	..
Mylepelian . .	50	26	15	1	1	..
Olour	50	11	11	..	..	..
Goa (Kasargod) . .	50	23	16	5	2	..
Kurakkan . . .	410	150	30	45	41	34

No study of the developmental morphology of the embryos in either the polyembryonic or the mono-embryonic varieties have yet been made. The observations so far made have been recorded here in the hope that these will be of sufficient interest to botanical workers in India so as to attract their attention to the problems of the mango.

SUMMARY

Observations on the relative times of growth and development of the fruit, seed and embryo in three varieties of mango, namely Bombai, Langra and Fazli, the occurrence of multiple shoots in germinated seeds of the same varieties, and polyembryony in five other varieties of Indian mangoes, namely Olour, Kurakkan, Goa (Kasargod), Mylepelian and Goa are herein reported.

Unlike in apple and in some temperate stone-fruits where the fruits develop in three well-marked stages (*i*) seed and fruit growth, (*ii*) embryo growth and (*iii*) final development of the fruit to maturity, the fruit, seed and the cotyledons of the embryo in mango grow concurrently.

Of the three first-named varieties, Bombai is an early ripener, maturing by the end of May ; Langra, a mid-season variety, maturing towards the end of June ; and Fazli, a late variety, ripening after the middle of July. The earlier the fruit is due to ripen, the more rapid is its rate of growth.

The radicle and plumule grow at a very slow rate till the end of May so that in the case of Bombai it shows no change in the rate at all; in the other two varieties, however, there is an abrupt rise in the rate of growth of the radicle and plumule after the first week of July. The two varieties show this change irrespective of their time of fruit-maturity. After some time the rate flattens out again so that the Langra mango shows no other change in this respect till its fruit matures, but in the case of Fazli the radicle and the plumule

how another abrupt rise in the rate of their growth after the first week of July. This rapid rate of growth results into a phenomenon like vivipary. The radicle and plumule sprout out of the stone and quite often attain a length of 20-25 cm.

In all the three varieties, i.e. Bombai, Langra and Fazli cases of multiple shoots and only one tap-root on germination of the seeds are found to occur. In the case of Fazli, seeds with multiple shoots are sometimes found in the ripe fruits. The extra shoots appear to arise adventitiously from the axils of the cotyledons.

All the polyembryonic varieties were found to have a few mono-embryonic seeds. The polyembryonic seeds always have one strong embryo and the others vary in vigour according to their positions in the seed. It appears probable that a considerable number of the polyembryonic seeds fail to successfully germinate more than one or two seedlings.

The necessity for an investigation of the behaviour of the zygote after fertilization in both the mono and polyembryonic varieties has been stressed because of the possibilities of improving them by hybridization and using the apogamically produced seedlings in the polyembryonic strains as clonal stocks.

Thanks are due to the Imperial Council of Agricultural Research, India for maintaining the Fruit Research Scheme under which it has been possible to make this study. Thanks are also due to Mr A. C. Sinha, B. Sc. Ac. for assistance in measurement work in 1938.

REFE RENCES

Arndt, C. H. (1935). *Amer. J. Bot.* Vol. **22**, 26-30
Belling, J. (1908). *Florida Agric. Exp. Stn. Ann. Rept.*, 110-25
Blake, M. A. (1925). *Proc. Amer. Soc. Hort. Sci.* **22**, 29-38
Connors, C. H. (1919). *N. J. Agric. Stn. Ann. Rept.* **41**, 82
Cook, M. T. (1907). *Torreya* **7**, 115-6
Juliano, J. B. and Cuevas, N. L. (1932). *Phil. Agric.* **21**, 449-72
Juliano, J. B. (1934). *Phil. J. Sci.* **54**, 553-61
———— (1937). *Phil. Agric.* **25**, 749-60
Lilleland, O. (1931). *Proc. Amer. Soc. Hort. Sci.* **28**, 237
Maheswari, P. (1934). *Current Sci.* **3**, 97
Mendiola, N. B. (1926). '*A mannual of plant-breeding for the tropics*': Manila, Bureau of Printing
Nandi, Tarachand (1934). *Current Sci.* **3**, 128
Sen, P. K. (1937). *Ann. Rept. East Malling Res. Sta.* 1936, 137
Strasburger, E. (1878). *Jenaische Zeitschr. Naturwiss* **12**, 647-70
Tukey, H. B. (1933). *Proc. Amer. Soc. Hort. Sci.* **30**, 309-19
———— (1937). *Proc. Amer. Soc. Hort. Sci.* **31**, 125-44

Appendix

TABLE A

Development of fruit, seed and embryo in mango, 1938

			Dates																	
			March		April				May				June					July		
			23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	6	13	20
Bombs	Fruit	Length cm.	0·96	...	4·40	5·60	6·90	7·40	8·60	9·50	10·20	10·70								
		Volume c.c.	0·90	...	25·30	53·30	90·50	117·5	149·4	206·7	255·40	257·60								
	Seed	Length cm.	0·50	...	1·70	3·00	4·00	4·80	5·00	6·20	6·70	6·60								
		Volume c.c.	0·10	...	0·90	3·90	7·90	12·10	14·10	20·80	22·00	27·00								
	*Embryo	Length cm.	...	0·80	1·50	2·70	3·90	4·70	5·70	6·20	6·50	6·30								
	Radicle & plumule	Length cm.	...	0·26	2·22	0·26	0·38	0·45	0·53	0·56	0·61	0·71								
Lanfra	Fruit	Length cm.	1·39	...	3·09	4·86	5·94	7·60	8·20	8·60	8·60	7·20	8·70	9·20	9·40	9·70	9·30	9·30		
		Volume c.c.	1·51	...	10·89	36·55	62·20	106·2	137·6	160·0	171·4	205·60	205·0	217·0	237·0	243·0	252·0	271·0		
	Seed	Length cm.	0·56	...	1·20	1·92	2·65	3·70	4·90	5·10	5·20	5·40	5·50	5·32	5·70	5·70	5·90	6·10		
		Volume c.c.	0·07	...	0·24	0·91	2·20	4·60	7·70	8·70	10·00	10·50	11·10	11·70	12·00	12·30	12·30	12·49		
	*Embryo	Length cm.	...	0·41	1·05	1·80	2·63	3·72	5·27	5·30	5·47	5·21	5·15	5·18	5·68	5·73	5·29	...		
	Radicle & plumule	Length cm.	...	0·06	0·11	0·24	0·27	0·37	0·50	0·46	0·58	0·50	0·50	0·47	1·94	1·96	1·94	...		
Fazli	Fruit	Length cm.	1·56	...	2·80	5·89	7·34	7·83	9·80	11·50	12·60	14·30	14·00	15·16	15·40	15·65	15·90	16·12	16·34	16·22
		Volume c.c.	1·93	...	7·80	48·85	87·70	102·1	170·4	277·5	349·7	450·0	518·0	628·0	642·00	650·2	658·3	708·2	724·9	775·0
	Seed	Length cm.	0·68	...	1·10	2·53	5·32	4·05	5·50	5·90	6·60	6·80	6·80	6·66	6·90	7·30	7·03	7·92	7·58	7·91
		Volume c.c.	0·36	...	1·26	2·19	4·07	4·35	10·10	15·00	20·00	21·00	21·00	21·80	26·70	29·20	32·0	32·70	26·60	38·10
	*Embryo	Length cm.	...	0·67	0·95	2·30	3·25	3·71	5·27	5·52	6·48	6·51	5·98	8·79	7·14	7·06	7·18	7·10	6·93	7·72
	Radicle & plumule	Length cm.	...	0·16	0·23	0·30	0·38	0·40	0·45	0·55	0·61	0·60	0·81	0·87	3·59	6·46	6·73	6·69	10·91	12·20

* Length in reality represents cotyledon length. No volume was measured in 1938.

TABLE B

Development of fruit, seed and embryo in mango, 1939

			Dates																
			March		April				May				June					July	
			23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	6	13
Bombai	Seed	Length cm.	...	3·31	4·17	5·79	5·88	6·14	7·68	8·17	7·82	8·41	8·50						
		Volume c.c.	...	11·72	18·20	53·00	57·60	75·00	126·6	54.7	154 7	168·8	175·6						
	*Embryo	Length cm.	...	1·36	2·03	3·65	3·90	4·28	5·54	5·80	5·66	5·72	5·74						
		Volume c.c.	...	0·39	1·33	5·10	6·84	11·60	13·60	15·86	15·50	16·40	16·00						
	Radicle & plumule	Length cm.	...	0·16	0·72	3·98	5·74	10·40	12·90	14·40	14·20	15·20	13·80						
		Volume c.c.	...	0·05	0·15	0·27	0·36	0·46	0·40	0·50	0·33	0·28	0·52						
Lanka	Fruit	Length cm.	...	2·83	5·07	5·83	6·42	7·04	7·15	7·72	8·57	8·54	8·74	8·56	9·74	9·94			
		Volume c.c.	...	5·64	40·50	56·60	80·80	120·0	121·4	129·2	211·2	216·0	235·0	239·8	240·6	245·0			
	Seed	Length cm.	...	1·10	2·37	3·10	4·30	5·40	4·48	5·06	5·97	5·68	5·84	7·70	5·82	6·18			
		Volume c.c.	...	0·24	1·80	3·28	8·62	12·90	12·00	12·60	1 ·83	15·00	17·20	17·60	20·10	20·60			
	*Embryo	Length cm.	...	0·73	2·24	2·96	4·10	5·32	4·76	5·02	5·90	5·66	5·71	5·60	5·50	6·00			
		Volume c.c.	...	0·06	1·30	2·36	7·12	11·80	11·10	11·60	12·60	14·00	14·40	15·50	15·30	17·00			
	Radicle & plumule	Length cm.	...	0·06	0·44	0·39	0·38	0·36	0·30	0·48	0·38	0·37	0·34	1·14	1·17	1·40			
Fiji	Fruit	Length cm.	2·10	2·35	4·26	5·50	6·56	6·52	9·20	10·10	16·60	11·50	12·54	16·40	15·20	15·12	15·02	15·20	14·20
		Volume c.c.	3·60	4·80	21·40	43·40	66·00	70·00	180·8	271·0	346·7	327·0	423·0	535·0	625·6	689·0	772·0	775·0	827·0
	Seed	Length cm.	0·90	1·00	2·07	2·70	3·48	3·56	6·40	5·56	6·36	5·72	6·52	6·74	7·62	7·50	7·51	7·39	7·83
		Volume c.c.	0·24	2·22	0·96	2·20	3·26	3·68	13·07	15·33	18·66	15·40	18·30	17·40	20·20	21·60	24·80	26·40	28·80
	*Embryo	Length cm.	0·57	0·45	1·87	2·54	3·28	3·36	4·80	5·44	6·30	5·60	6·64	6·72	7·16	7·20	7·00	7·25	7·67
		Volume c.c.	0·05	0·05	0·61	1·50	2·30	2·76	11·80	13·80	14·60	14·40	16·70	16·20	18·10	19·20	22·40	24·50	26·90
	Radicle & plumule	Length cm.	0·05	0·10	0·19	0·26	0·35	0·32	0·42	0·42	0·62	0·61	0·76	3·39	3·52	3·59	5·52	10·00	12·4

* Length in reality represents cotyledon length.

THE EFFECT OF AMMONIACAL AND NITRATE NITROGEN ON THE YIELDS OF THE RICE PLANT

BY

R. H. DASTUR

Punjab Agricultural College, Lyallpur

(Received for publication on 19 May 1939)

DURING the investigations on the physiology of the rice plant carried out at Bombay it was found that from water-culture solutions the absorption of ammoniacal nitrogen by the rice plant decreases while that of the nitrate nitrogen increases as the plant ages [Dastur and Malkani, 1933]. It was, therefore, concluded that a mixture of two forms of nitrogen would be a better source of available nitrogen to the rice plant than any one of them applied singly, after transplantation. Pot experiment and small plot experiments later confirmed the above conclusion [Dastur and Pirzada 1933]. It was also found that maximum effect on the growth and yield of the rice plant was produced when a mixture of sulphate of ammonia and potassium nitrate was applied one month after transplantation (i.e., middle of August).

When the above-mentioned findings were discussed by the Rice Sub-Committee of the Imperial Council of Agricultural Research, it was suggested that the superiority of the mixture of ammonium sulphate and potassiulm nitrate to any one of the two fertilizers applied on an equal nitrogen basis might be due to the presence of potassium and not to the greater availability of nitrogen in the mixture used. In order to meet this fresh view point it was decided to use sodium nitrate in place of potassium nitrate. Field experiments with necessary replications were therefore arranged at two places in the Bombay Presidency with the following four treatments which were randomised ; (A) control, (B) sodium nitrate, (C) ammonium sulphate and (D) mixture of (B) and (C) on equal nitrogen basis. Nitrogen was applied at the rate of 40 lb. of nitrogen, in all cases, one month after transplantation. The results of these field experiments as given in Table I showed that in the light soils at Goregaon (Thana district) the mixture of ammonium sulphate and sodium nitrate gave significantly higher yields of grain than ammonium sulphate or sodium nitrate alone while the increase in grain yield resulting from ammonium sulphate over that of the control was just on the verge of significance. No significant difference was found between the grain yields from sodium nitrate and the control. The yields of straw on Goregaon soils were in the order :—mixture>ammonium sulphate>sodium nitrate>control. On heavy soils at Talangpur (Surat district) the case was different. On these soils ammonium sulphate was found superior to the mixture of two fertilizers and gave a significant increase in yields of grain. The mixture gave higher yields than sodium nitrate and sodium nitrate gave higher yields than the control.

In case of straw yields ammonium sulphate was found equal to mixture while the other treatments gave similar results as on soils at Goregaon.

From the results obtained it was clear that at one place the mixture proved better than ammonium sulphate while at the second place ammonium sulphate gave higher yields than the mixture treatment. It was then suggested

by the author that these differences in response to these two treatments at these two places might be due to the differences in the physical and chemical properties of the soils (*Prog. Reports, I. C. A. R.*, 1934).

TABLE I

Place	Treatments	Mean yields of grains in lb. per acre	Mean yields of straw in lb. per acre	Conclusions
Goregaon (Thana district), Bombay	A. Control	1,382	1,894	Mixture is superior to ammonium sulphate
	B. 40 lb. of N as sodium nitrate	1,306	2,265	
	C. 40 lb. N as ammonium sulphate.	1,516	2,983	
	D. 20 lb. N as sodium nitrate + +20 N as ammonium sulphate.	2,001	3,582	
	S. E. of a single mean . .	55·9	73·1	
Taiangpur (Surat district), Bombay	A. Control	1,505	1,842	
	B. 40 lb. N as sodium nitrate .	1,685	2,276	Ammonium sulphate is superior to mixture
	C. 40 lb. N as ammonium sulphate.	2,276	3,150	
	D. 20 lb. N as sodium nitrate +20 lb. N as ammonium sulphate.	2,033	2,919	
	S. E. of a single mean . .	124·0	212·0	

In 1934 the above quoted results were discussed by the Rice Sub-Committee of the Imperial Council of Agricultural Research and it was then recommended that the Agricultural Departments of the different provinces may find it worthwhile to test this conclusion of superiority of a mixture of ammonium sulphate and sodium nitrate on some soils to either constituent as a fertilizer for rice.

The investigations at Bombay could not be continued on account of the transfer of the author to the Punjab and further investigations on the properties of the soils giving different responses to the mixture treatment as compared with ammonium sulphate could not be undertaken. But in view of the recommendations of the Imperial Council of Agricultural Research the Agricultural Departments of some provinces laid out field experiments to test the above-quoted conclusion.

The yield results of the field experiments carried out at different agricultural stations in India have now been made available to the author for examination in the light of the conclusions reached by him at Bombay.

The field experiments were carried out at the agricultural research stations in Assam, United Provinces, Bombay, Orissa, Bihar, Madras and in Travancore State. The experiments were either conducted for one, two or three consecutive years in each province at one or more places. It may be mentioned here that experiments laid out at different places differed in one or more respects from one another. As for instance at Raipur in C. P. treatments given were different from those recommended. The doses of nitrogen given also varied, and so also the time of applications of the fertilizers. The number of replications differed at different places. On account of lack of homogeneity in the conduct of experiments no further statistical study of the results than discussed below was possible.

The yield results with conclusions in brief are given in Tables II-IV. A study of these results show a few irregular features which are pointed out later.

TABLE II

Treatments	Mean yields per acre in lb.	Conclusions
TITABAR (ASSAM) *1932*		
A. Control . .	2,674	Mixture is superior to amm. sulphate.
B. 40 lb. N as pot. nitrate.	2,770	
C. 40 lb. N as amm. sulphate.	2,475	
D. 20 lb. N as pot. nitrate + 20 lb. N. as amm. sulphate.	2,875	
MUGHAD (BOMBAY) *1935*		
A. Control . .	2,057	*No effect of treatments.
B.* ———	...	
C. 40 lb. of N as amm. sulphate.	1,997	S. E. not stated.
D. 20 lb. N as sod. nitrate + 20 lb. N as amm. sulphate.	1,997	

Treatments	Mean yield per acre in lb.	Conclusions
NAGINA (U. P.) *1935*		
A. Control . .	2,234	Mixture is as good as amm. sulphate alone.
B. 50 lb. N as sod. nitrate.	2,181	
C. 50 lb. N as amm. sulphate.	2,535	S.E. = 124·8 lb.
D. 20 lb. N as sod. nitrate + 20 lb. N as amm. sulphate.	2,617	
1936		
A. . . .	2,311	Amm. sulphate alone is as good as mixture.
B. Same as above .	2,554	
C. . . .	3,112	S. E. = 70·1 lb.
D. . . .	2,937	

Treatments	Mean yields per acre in lb.	Conclusions
CUTTACK (BIHAR) *1935*		
A. Control . .	3,373	Amm. sulphate alone is as good as mixture.
B. 40 lb. N as sod. nitrate.	3,537	
C. 40 lb. N as amm. sulphate.	3,772	S.E. = 145·17 lb.
D. 20 lb. N as sod. nitrate + 20 lb. N as amm. sulphate.	3,656	
1936		
A. . . .	1,980	Amm. sulphate is as good as mixture.
B. As above . .	2,311	
C. . . .	2,478	S.E. = 72·4 lb.
D. . . .	2,344	

TABLE III

Mean yields per acre in lb.

Treatments	1933-34		1934-35		1935-36		Conclusions
	Sandy soil	Clayey soil	Sandy soil	Clayey soil	Sandy soil	Clayey soil	
Raipur (C. P.)							
1. 20 lb. N as amm. sulphate at transplantation.	1,011	933	1,475	1,025	2,084	...	No effect of treatments.
2. 10 lb. N + 10 lb. N as amm. sulphate at transplantation and at flowering.	949	586	1,349	1,103	1,988	...	
3. 10 lb. N as amm. sulphate + 10 lb. N as sodium nitrate at transplantation.	973	624	1,347	1,098	1,998	...	
4. 10 lb. N as amm. sulphate at transplantation + 10 lb. N as sodium nitrate at flowering.	998	569	1,378	1,048	1,991	...	
	S. E. not given		S.E. 132 lb.	162·9 lb.	148·2 lb.		

Kanke (Bihar)

	1935-36		1936-37		1937-38		
	Transplanted	Broadcast	Transplanted	Broadcast	Transplanted	Broadcast	
A. Control . .	311	661	1,219	1,086	302	756	In 1935-36 and 1936-37 amm. sulphate is superior to mixture but in 1937-38 mixture is found superior to amm. sulphate. In 1937-38 sodium nitrate is found to be the best treatment.
B. 40 lb. N as sodium nitrate.	513	486	1,361	1,095	1,210	1,473	
C. 40 lb. N as amm. sulphate.	428	804	1,890	2,135	681	1,176	
D. 20 lb. N as sodium nitrate + 20 lb. N as amm. sulphate.	408	466	1,509	1,576	717	1,436	
	S. E. not known						

At Mughad in Bombay yields show no effect of treatments. The yields of control are slightly higher than the plots treated with 40 lb. of nitrogen and will therefore be not discussed. The results obtained at Raipur in the Central Provinces could not be correctly interpreted as no control is provided for and it is difficult to know if application of nitrogen in any form has any effect at all. The results obtained at Kanke indicate great differences in the responses to sodium nitrate. In 1935-36 sodium nitrate has given the highest yields in case of transplanted paddy but in case of broadcast paddy the same treatment has depressed the yields. In 1937-38 on the other hand

sodium nitrate has proved the most superior treatment in both cases, while in 1936-37 this is not the case. It is likely that in 1935 in case of broadcast paddy sodium nitrate may have caused injury to the rice seedlings at the time of application and thus the yields were depressed. Such injury to plants is known to be caused when sodium nitrate is applied.

TABLE IV

Treatments	Coimbatore	Maruteru	Aduturai	Berhampur	Conclusions
	Yields expressed as percentages of general mean for 1935-36 and 1936-37				
A. Control	125·7	93·1	123·3	70·9	Amm. sulphate is as good as the mixture.
B. 30 lb. N as sodium nitrate	134·5	69·5	139·2	80·5	
C. 30 lb. N as amm. sulphate	157·8	69·9	152·4	90·0	
D. 15 lb. N as sodium nitrate +15 lb. N as amm. sulphate.	149·4	70·5	147·5	90·0	
E. 20 lb. N as amm. sulphate +10 lb. N as sodium nitrate.	153·1	69·8	144·8	84·6	
F. 10 lb. N as amm. sulphate +20 lb. N as sodium nitrate.	139·7	70·7	146·5	82·2	
	S. E. = 3·6	Critical difference = 10·2			

In Madras the experiment to determine the response to a mixture of two fertilizers was laid out for two years 1935-36 and 1936-37 at four different agricultural stations. In addition to the usual four treatments two more combinations of ammonium sulphate and sodium nitrate were tried as separate treatments. At Maruteru Farm the experiment was spoiled in 1936-37 on account of the incidence of silver shoot disease and controls yielded more than the plots treated with nitrogen.

Table V shows how the mixture and ammonium sulphate treatments have responded at different places in different years.

TABLE V

Mixture > amm. sulphate	Goregaon (Bombay)	Titabar (Assam)	Kanke (Bihar)	Travancore
	1933-34	1932	1937-38	1936-37
Amm. sulphate > mixture	Kanke (Bihar)	Talangpur (Bombay)		
	1935-36 1936-37	1933-34		
Mixture = amm. sulphate	Nagina (U. P.)	Cuttack (Orissa)	Raipur (C. P.)	Madras
	1935-36 1936-37	1935-36 1936-37	1933-34 1934-35	1936-37
Sodium nitrate > amm. sulphate = mixture	Kanke (Bihar)			
	1937-38			

The responses to the mixture and ammonium sulphate at different places are different. At four stations mixture was found superior to ammonium sulphate in a total of six experiments. There was no difference between the mixture and ammonium sulphate in a total of twelve experiments at six stations while ammonium sulphate was found superior to mixture in a total of five experiments at two stations. There was no response to any fertilizer at one station while it is not possible to say whether there was any response to applications of nitrogen at another station. At the latter place no difference between the mixture and ammonium sulphate treatments was found. Thus mixture was found superior to ammonium sulphate in six experiments out of a total of twenty-nine experiments, inferior to ammonium sulphate in five experiments and equal to ammonium sulphate in twelve experiments. It is thus clear that responses to mixture and ammonium sulphate varied from place to place as was the case in the field trials carried out by the author at two places in Bombay.

The results suggest that the differences in the response to these treatments at different places may be due to the differences in the physical and chemical properties of the soil. They may also be due to the different effects produced by the sodium ions of sodium nitrate in different soils. It was pointed out in the earlier part of the paper that originally a mixture of ammonium sulphate and potassium nitrate was used but to meet the view point that greater response given by the mixture to either constituent might be partly due to the presence of potassium ions in the mixture, potassium nitrate was replaced by sodium nitrate. But this change from potassium nitrate to sodium nitrate very likely introduced other disturbances in the soil. It is known that from a solution of sodium nitrate, nitrate ion is absorbed to a greater extent than sodium ions and the soil reaction is altered as found by the author [Dastur and Kalyani, 1934]. In case of potassium nitrate this is not the case. It was found by the author [Dastur and Malkani, 1933] that potassium ion is absorbed by the rice plant to a greater extent than the nitrate ion from a solution of potassium nitrate. It is thus possible that presence of sodium nitrate in the mixture may have adversely affected the activities of the roots in certain soils and has thus lessened the yields at some places.

The above-mentioned point can be elucidated by laying out a complex experiment involving all combinations of potassium nitrate, sodium nitrate and ammonium sulphate. There will be $(2)^3$=eight treatments: (1) control; (2) potassium nitrate; (3) sodium nitrate; (4) ammonium sulphate; (5) potassium nitrate+sodium nitrate; (6) sodium nitrate+ammonium sulphate; (7) potassium nitrate+ammonium sulphate; (8) potassium nitrate+sodium nitrate+ammonium sulphate. Such an experiment will at once show the effects produced on the plants by the presence of potassium and sodium ions in the mixture.

Summary

Field trials on rice were arranged to study the response made by sulphate of ammonia, sodium nitrate and a mixture of two fertilizers, on equal nitrogen basis at different places in India to test the authors' finding from a purely physiological study, that mixture of two fertilizers is a better source of nitrogen in some soils than any one of the two constituents used separately.

The experiments were laid for two or three years in Bihar, Orissa, Centra Provinces, Madras, Bombay, Assam and Travancore during the period 1933-37. The statistical analyses of the results showed that the mixture gave significantly higher yields than ammonium sulphate at Goregaon (Bombay), Titabar (Assam), Kanke (Bihar) and Travancore ; ammonium sulphate gave significantly higher yields at Kanke (Bihar) and Talangpur (Bombay) ; the mixture was found as good as ammonium sulphate at Nagina (U. P.), Cuttack (Orissa), Raipur (C. P.) and Coimbatore, Aduturai and Berhampur (Madras). Sodium nitrate gave significantly higher yield than the mixture or ammonium sulphate at Kanke (Bihar) in 1936-37. The field experiments arranged at two places in Bombay by the author had also shown that the response to the mixture and ammonium sulphate varied in different soils.

It is suggested that presence of sodium ions in sodium nitrate used may have produced some deleterious effects in certain soils and thus the response to mixture may have been lessened at such places resulting in no increase in the yields when compared with ammonium sulphate. A complex experiment involving all combinations of potassium nitrate, sodium nitrate, ammonium sulphate and control will elucidate this point in such soils.

Acknowledgments

The statistical interpretations of the yield results discussed in this paper were done by Rao Bahadur M. Vaidyanathan, Statistician, Imperial Council of Agricultural Research and the experiments were conducted by the staff of the respective agricultural departments of the different provinces and states.

REFERENCES

Dastur, R. H. and Kalyani, V. V. (1934). *Ind. J. Agric. Sci.* **4**, 803-31

Dastur, R. H. and Malkani, T. J. (1933). *Ind. J. Agric. Sci.* **3**, 157-206

Dastur, R. H. and Pirzada, A. R. (1933). *Ind. J. Agric. Sci.* **3**, 963-1012

CARBON TRANSFORMATIONS DURING THE DECOMPOSITION OF CANE MOLASSES UNDER SWAMP SOIL CONDITIONS

BY

G. NARASIMHAMURTHY

Department of Biochemistry, Indian Institute of Science, Bangalore

(Received for publication on 8 December 1939)

(With one text-figure)

LABORATORY studies on the effect of addition of cane molasses to various representative Indian soils under swampy conditions have shown that carbohydrate, the major constituent of molasses, rapidly undergoes decomposition, yielding a variety of products, some of which escape into the air as gases, the others remaining in solution [Bhaskaran *et al.*, 1934, Karunakar *et al.*, 1937]. To understand the nature of the decomposition products contributing to the fertilizing value of the molasses, it becomes necessary to carry out a systematic examination of such products throughout the period during which the fermentation is in progress. The results of the studies relating to the gaseous products of the breakdown of the soil molasses complex have already been published [Narasimhamurthy, 1936]. An examination of the soil residues [Narasimhamurthy and Subrahmanyan, 1935] in these studies revealed that the final carbon level remained unaltered except in those cases where the system was alkaline. In this latter case, the carbon level fell down to a great extent. In the initial stages of the fermentation, however, there is a distinct rise in the carbon level of the soil. It is therefore clear that the significant changes are confined to the solution phase and in this paper the results of a detailed study of the changes in carbon complex in the solution phase are recorded.

EXPERIMENTAL

Materials

FOR these studies, the local red sandy loam soil was employed. After removing the roots and other vegetable residues present in it, the soil was pulverised and sieved. The fraction which passes through 20 mesh but not through 30 mesh was separated out for reasons given in our previous work [Bhaskaran *et al.*, 1934] for use in the experiments. The soil used in the present study was obtained from the same plot from which samples had been drawn for the previous investigations [Bhaskaran *et al.*, 1934]. The experiments were carried out during the months of August-September and the temperature during the period varied between 90° and 70°F.

Procedure

The soil was weighed out in 400 gm. lots into bottles of about 2 litres capacity. To each lot was then added 4 gm. of molasses and one litre of water. This proportion of water was found sufficient to keep the soil well submerged. The bottles were loosely plugged with cotton wool. Two series of experiments were conducted. The first, which was qualitative in character, had for

its objective the identification of the products of decomposition in the liquid phase. This experiment lasted for four weeks and random samples were taken for examination each day in the first week and once a week later. In the second series, the more important constituents were quantitatively estimated ; samples were taken for analysis every other day throughout the period.

The supernatant liquid was separated from the soil residue by filteration on a Buchner under gentle suction. The residue on the filter was washed three times with liberal quantities of distilled water and the combined filtrate and washings employed for the analysis. The solution was first made alkaline in order to precipitate iron and after filtration and repeated washing of the precipitate, the filtrate and washings were distilled to remove the neutral volatile products. Ice-cold water was employed to cool the receiver and the condenser. The distillate was made up to a known volume and aliquots used for estimating alcohol and aldehyde. The residual solution in the distilling flask was quantitatively transferred into a clean porcelain basin, made alkaline to litmus and evaporated on a water-bath to a small bulk. It was then made up to a known volume and aliquots used for estimating lactic acid and volatile fatty acids.

Methods

Qualitative examination revealed the presence of the following acids :— lactic, acetic, propionic and butyric. Alchol and aldehyde were the only neutral bodies detected.

Alcohol and aldehyde.—Aldehyde was estimated by the method of Fidler [1934]. Briefly stated, the method consists in treating the aldehyde solution with sodium bisulphite at 0°C. for one hour and back-titrating the unused bisulphite with standard iodine solution. The observation of Fidler [1934], that under these conditions auto-oxidation of aldehyde is negligible, is confirmed in the present work. It was also found that alcohol does not interefere in the estimation.

Alcohol and aldehyde were together estimated in a separate aliquot. They were oxidised by excess of standard dichromate solution at 37°C. in an incubator for forty-eight hours, the residual dichromate being estimated by titration with standard thiosulphate. Subtracting from this the known value for aldehyde, the quantity of alcohol present in the mixture was computed.

Lactic acid.—The method was essentially the same as that outlined by Subrahmanyan [1929]. Preliminary experiments showed that the method was quite suitable for the determination of lactic acid in the decomposition products of molasses, and that the presence of volatile fatty acids, such as propionic and butyric acids, did not interfere with the accuracy of the method.

Fatty acids.—Volatile fatty acids were estimated according to the procedure outlined by Dyer [1916].

Results

For the qualitative study the culture solution was examined both before and after separation from the soil sediment. In the latter the solution was fractionated into three portions through distillation : (1) the non-volatile residue in the flask, (2) the volatile acids and (3) the volatile neutral products of fermentation. In the non-volatile portion, tests were made for lactic, peruvic and succinic acids. Volatile fatty acids were looked for in the

second fraction and tests were applied to the third portion for acetone bodies alcohols and aldehydes among the netutral volatile products.

Reducing sugars persisted till the third day. Lactic acid and alcohol were present in the solution after the first twenty-four hours. The solution also gave a faint idoform reaction in the cold indicating the presence of acetone bodies, but other tests showed that this was not due to acetone. The reaction was noticed on the second day also but subsequent samples did not answer this test. On the second day, in addition to lactic acid and alcohol, both propionic acid and acetic acid were present, the latter only in traces. The following day aldehyde was the only additional compound identified ; the test for acetic acid was stronger than on the second day. The same tests were obtained throughout the week with only one addition, viz. that of butyric acid which appeared to be in traces. The indication for aldehyde was also weak. During the following two weeks the products persisted with the exception of aldehyde and butyric acid. Towards the end of the last week of the experiment, i.e. on the twenty-eighth day, only three products were found to be present and these were alcohol, lactic acid and acetic acid. They too were present only in diminished quantities.

In the other series, where a quantitative estimation of the fermentation products was carried out, the experimental period was restricted to about three weeks, the reason being that in actual field practice the fields are flooded after this period, and the soluble products get completely washed away. In these estimations attention was given to aldehyde, alcohol, lactic, acetic, propionic and butyric acids. The results are given in Table I and graphically represented in Fig. 1. The quantities of aldehyde and butyric acid in the solution being of the order of 1 mg. and below were omitted from the table.

TABLE I

Balance sheet for carbon in the changes accompanying the decomposition of molasses (expressed on 100 gm. of soils)

Serial No. of experiment	Period of fermentation in days	Total carbon added as molasses (mg.)	Carbon recovered as						
			Sugar	Alcohol	Acetic acid	Propionic acid	Lactic acid (mg.)	Carbon dioxide* (mg.)	Total carbon recovered (mg.)
1	0	307	...	...	...	...	...	...	307
2	2	,,	31	64·5	13·2	17·4	31·5	22.0	...
3	4	,,	Nil	16·5	22·0	97·7	36·0	66.0	238·4
4	6	,,	,,	20·0	12·0	40·5	47·7	90·5	211·0
5	8	,,	,,	9·0	...	...	...	100.0	...
6	10	,,	,,	7·0	58·7	134·0	21·7	103.0	324·5
7	12	,,	,,	4·0	111·0	79·0	20·5	106.0	320·7
8	14	,,	,,	2·5	83·5	107·0	22·2	107·4	322·6
9	16	,,	,,	0·6	85·0	136·0	13·6	109·0	344·3
10	18	,,	,,	0·9	104·0	98·7	19·0	111·2	333·9
11	20	,,	,,	1·3	66·0	118·0	12·0	114·0	311·5
12	22	,,	,,	0·9	80·0	118·0	3·5	120·5	323·0

* Results in this column are reproduced from a previous paper [Bhaskaran *et al.*, 1934].

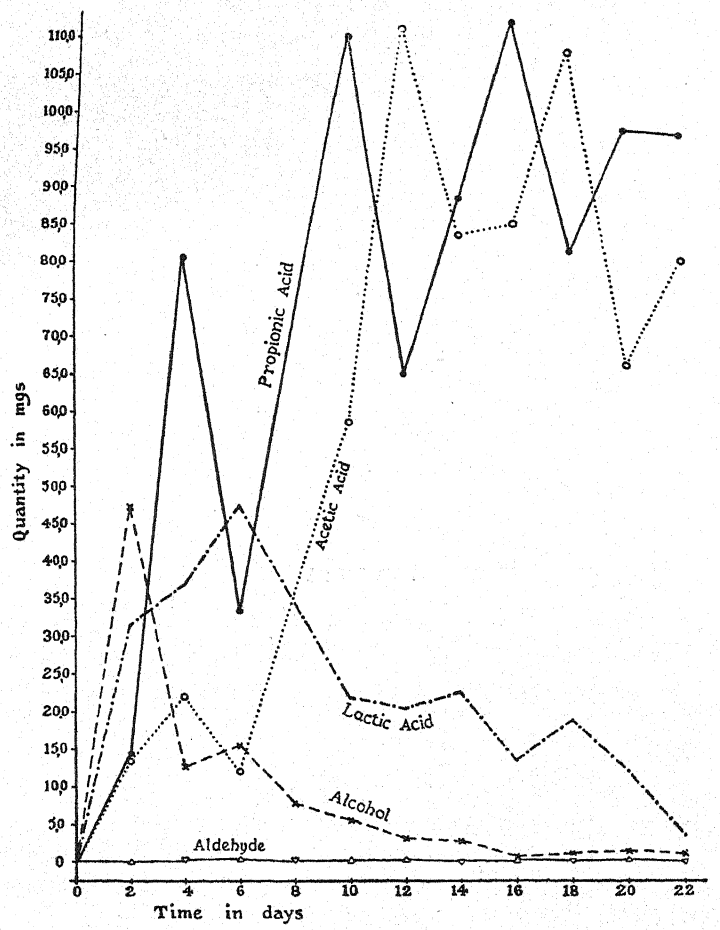


FIG. 1.

DISCUSSION

The results presented show that the carbonaceous matter of molasses is largely converted into gases like carbon dioxide and methane and other organic compounds which being soluable are present in the supernatant liquid. The carbon content of the soil is not, however, enhanced as there is little or no humus production. This observation is in conformity with the previous findings [Narasimhamurthy and Subrahmanyan, 1935].

Of the several soluble compounds formed, organic acids form the bulk and the quantity produced particularly that of acetic and propionic acids is considerable during the second half of the experiment. The large amounts of acids present lowers the *p*H markelly, rendering the soil highly acidic. This is in conformity with the observations in the earlier work [Bhaskaran *et al.*, 1934] wherein it was shown that the *p*H and buffering capacity of the supernatant liquid reach a peak by about this period. Due to this acidity no crop can thrive on the soil during this period. The toxic effect ascribed to molasses-treated soil and the unfavourable results reported by Peck [1912], Harrison and

Wad [1913] may be due to this condition. Karunakar *et al.* [1937] ascribe the toxicity to the gases carbon dioxide and hydrogen which displace oxygen from the soil solution and thus as phyxiate the plant.

The presence of these acids in such concentrations would naturally alter the physical condition of the soil by reacting with its insoluble mineral complex. Considerable quantities of iron, calcium and aluminium are brought into solution [Bhaskaran *et al.*,1934].

Of considerable interest are the chain of fermentation products produced under the conditions of the experiment, in the succession mentioned already. Lactic acid is the first to be produced. The other acids are probably derived from it as a result of decomposition. The observation that the concentration of volatile acids increases with the decrease in the concentration of lactic acid lends support to this assumption. However a definite assertion on this point is not possible with the available data.

In view of the high carbon-nitrogen ratio obtaining in molasses, there is considerable loss of carbon. If by the addition of suitable nitrogenous matter, the C/N ratio is narrowed down, a portion of carbon could probably be retained in the soil but this however is a field for further investigation.

Summary

1. The transformation of molasses, when applied to soil as a manure under waterlogged conditions, has been studied.

2. The carbon reserves of the soil are not augmented by using molasses as a manure. The acidity of the supernatant solution becomes so high as to render the soil unsuitable for the crop for at least one month after the application of molasses.

3. The decomposition products are mostly acids such as lactic, acetic, propionic and butyric, the last mentioned occurring only in traces. Alcohol is also found to occur in appreciable quantities These decomposition products together with carbon dioxide which escapes from the system as gas account for nearly all the quantity of carbon added as molasses.

4. Lactic acid is the first product of the decomposition of molasses in soil. Other products appear later. The concentration of lactic acid gradually decreases while that of other acids increase.

The author's grateful thanks are due to Prof. V. Subrahmanyan for his helpful suggestions in the course of this investigation and to Mr B. N. Banerjee fo his kind interest.

REFERENCES

Bhaskaran, T. R., Narasimhamurthy, G., Sundara Iyengar, B. A., and Subrahmanyan V. (1934). *Proc. Ind. Acad. Sci.* **IB**, 155

Dyer, D. C. (1916). *J. Biol. Chem.* **28**, 485

Fiddler, J. C. (1934). *Biochem. J.* **28**, 1107

Harrison, J. B. and Wad, Y. D. (1913). *Internat. Sug. J.* **16**, 373

Karunakar, P. D., Sanyasiraju, M., Rajagopalan, T. and Sundaram, M. (1937). *Proc. Assoc. Econ. Biol.* **5**

Narasimhamurthy, G. (1936). *Curr. Sci.* **4**, 346

Narasimhamurthy, G. and Subrahmanyan, V. (1935). *Proc. Ind. Acad. Sci.* **IB**, 823

Peck, S. S. (1912). *Internat. Sug. J.* **15**, 353

Subrahmanyan, V. (1929). *J. Agric. Sci.* **19**, 627

ON THE INDEX OF NITROGEN LEVEL IN SOILS

BY

P. E. LANDER, D. Sc., F. I. C., I. A. S.
Agricultural Chemist to Government, Punjab Lyallpur

AND

M. R. MADHOK, Ph. D., Assoc. I. A. R. I.
Agricultural Bacteriologist, Punjab Agricultural College, Lyallpur

(Received for publication on 5 July 1940)

SINCE the discovery of nitrogen-fixing bacteria, workers in many countries have made attempts to evaluate the extent and significance of nitrogen fixation in soils under different conditions. There are cogent reasons to believe that fixation occurs in arable soils and the most direct proof is the continuous crop yields from soils which have never been manured within human memory. Potash is abundant in most soils and phosphoric acid can be brought from the sub-soil by the deeper roots of plants, so a fair level of fertility can be maintained if the nitrogen supply is kept up. In soil where no nitrogenous manure has been added the supply of nitrogen must be entirely due to nitrogen-fixing organisms.

The extent of asymbiotic nitrogen fixation has been fixed within considerable limits in the vast literature on the subject. Two plots at the Rothamsted Farm have shown an average fixation of 25 lb. of nitrogen per acre annually over a period of twenty-five years [Hall, 1937], while another plot left wild under permanent vegetation on the same farm has shown an average annual fixation of 91·7 lb. nitrogen per acre during fifty years [Russell, 1937]. In the Punjab, Wilsdon and Ali [1922] recorded an increase of over 100 per cent nitrogen in four months in some districts ; the maximum fixation recorded being 50 mg. nitrogen per 100 gm. soil or equivalent to 150 tons farmyard manure per acre. Lander and Ali [1925] from the same laboratory corroborated the above findings on the nitrogen-fixing power possessed by arable soils, but were not able to record such high additions. They on the other hand found that losses of the nitrogen fixed also took place as rapidly.

Considering the losses of nitrogen otherwise than by leaching from arable soils, one plot at Rothamsted has received an application of 14 tons of farmyard manure or 200 lb. nitrogen every year since 1865 ; of this huge amount of nitrogen only about one-fourth has been obtained in the crop, another one-fourth is detectable in the soil and the rest is supposed to have been lost.

Besides the innumerable reports of gains and losses of nitrogen from arable soils there are instances on record where no significant fixations or losses could be recorded [Punjab Department of Agriculture Reports, 1917-20]. While there can be several explanations of differences in observations under different conditions, the chief reason for such widely differing observations seems to be

the method that is commonly used for the determination of nitrogen in soil. That most commonly used is the Kjeldahl method which is based on the transformation by acid digestion of the different forms of nitrogen into ammonium sulphate from which ammonia is later distilled in standard acid. Generally 5 to 10 gm. of soil samples are used for analysis and the ammonia evolved during distillation is received in a deci-normal acid.

In actual practice it is possible even with the utmost care to use a drop of alkali too much or too little before the end point is well marked in titration. Taking four million pounds as the average weight of an acre-foot soil this difference of a drop of alkali in titration represents 56 lb. of nitrogen more or less per acre if a 5-gm. sample is used for analysis or 28 lb. nitrogen if the sample taken for analysis is 10-gm.

(Approximate weight of one acre-foot soil

$$= 4{,}000{,}000 \text{ lb.}$$

$$\text{or } \times 453 = 1{,}812{,}000{,}000 \text{ gm.}$$

Difference of a drop of deci-normal alkali for 5-gm. sample means a difference of one c.c. in 100 gm.— or 1·4 mg. N per 100 gm. soil

$\therefore$ difference in acre-foot soil—

$$= \frac{1{,}812{,}000{,}000 \times 1{\cdot}4}{1000 \times 100}$$

$$= 25{,}368 \text{ gm. N}$$

or 56 lb. N per acre)

Taking 45 lb. as the average nitrogen content of a wheat crop removed from one acre it will be seen that even the most careful worker cannot detect with certainty the gain or loss of this amount in the soil.

In order to illustrate this point a number of determinations were carried out with a sample of clay-loam soil. A portion of the sample was sieved through a 0·5-mm. sieve, another portion sieved through a 1-mm. sieve and still another portion sieved through 2-mm. sieve. Determinations of nitrogen were made in 5 and 10 gm. portions of the three samples so prepared and the following results were obtained :

NITROGEN IN LB. PER ACRE

I. As affected by the size of particles (10-gm. sample used for determination).

Sieve used	0·5 mm.	1 mm.	2 mm.
Dry digestion	1316	1330	1372
*Wet digestion	1372	1358	1400

II. As affected by the weight of sample taken for analysis (1-mm. sieved sample).

	Dry digestion	Wet digestion*
5 gm.	1400	1344
10 gm.	1330	1358

* In wet digestion the soil was treated with 20 c.c. water before the addition of acid.

Without discussing the comparative merits and demerits of the wet and dry methods of digestion or the influence of the weight and fineness of the sample taken for analysis, the above-quoted results clearly show how variable the results of nitrogen determination in soil can be in spite of neat care.

While standardization of the procedure similar to the one suggested by the Official Agricultural Chemists may help to make the results more comparable, the Kjeldahl method is not at all suitable for recording absolute fluctuations of nitrogen in soil.

REFERENCES

Hall, A. D. (1937). '*The feeding of crops and stock, Part II. Soils and fertilizers*': John Murray, p. 82

Lander, P. E. and Ali, B. (1925). *Mem. Dept. Agric. Ind.* (*Bact. Ser.*) **2**, No.1

Russell, E. J. (1937). '*Soil conditions and plant growth*,' p. 379

Wilsdon, B. H. and Ali, B. (1922). *Soil Sci.* **14**, 127-34

EUPELMELLA PEDATORIA FERR., A PARASITE OF THE COTTON-STEM WEEVIL (*PEMPHERES AFFINIS* FST.) FROM SOUTH INDIA

BY

P. N. KRISHNA AYYAR

Parasitologist, Agricultural College and Research Institute, Coimbatore

(Received for publication on 19 July 1938)

(With Plate XXXV and three text-figures)

INTRODUCTION

IN the course of an investigation into the possibility of the biological control of the cotton-stem weevil of South India, the biology of *Eupelmella pedatoria* Ferr., an ectophagous larval parasite of this weevil, was studied. This curious eupelmid was for the first time observed parasitising *Pempheres* grubs in an off-season crop of Cambodia cotton during July 1937. It has since been recovered, though in small numbers, on several occasions from the same crop and from the same host as also from other hosts infesting a few other species of plants. The study is by no means exhaustive since many aspects of its biology and distribution still require a more thorough and extended investigation. This is perhaps the first record of this genus in India. Besides, the parasite was noted to be peculiar and unique in respect of certain structural characters, reproductive habits and parasitism. It was therefore thought desirable to place on record the fact of its occurrence in this country together with the observations so far made on its life-history and behaviour in relation to its host complex.

Adult (*Plate XXXV fig. 1*).—The adult female is a dark smooth shining elongate creature varying in size from 1·0 mm. to 3·6 mm. in length, averaging 2·6 mm. with a width varying from 0·5 mm. to 0·75 mm., averaging 0·6 mm. for six individuals. The general colour varies from brownish dark to jet black. The wings are rudimentary and curved with a narrow tapering apical region. Consequently the parasite is unable to fly. The parasites, however, are adepts in running quickly and taking long leaps in cages. The ovipositor is quite prominent and well extended beyond the tip of the abdomen.

The specimens were sent to the Imperial Institute of Entomology, London, for identification and Dr Ferriere has recently determined the same as a new species of *Eupelmella*—family Eupelmidae, super-family Chalcidoidea, [Ferriere, 1939].

HISTORY OF THE GENUS

The genus *Eupelmella* was first erected by Moore in 1919 and named *Eupelmus degeeri* Dalman as the genotype. As seen from available literature the genus appears to be small including so far only two species of economic importance, *Eupelmella vesicularis* Retz. and *E. platycleidis* Sarra. The

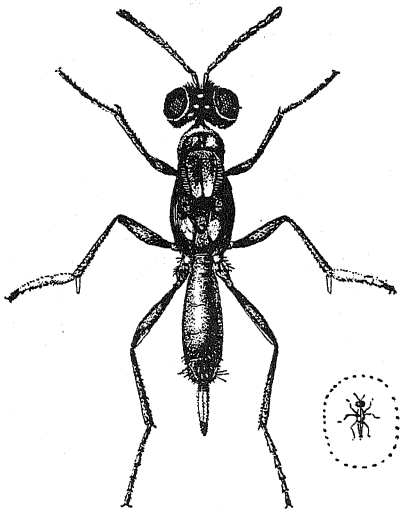


FIG. 1. Adult female (×12)



FIG. 2. Egg (×59)

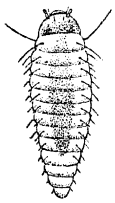


FIG. 3. First stage larva (×40)

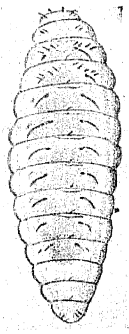


FIG. 4. Full-grown larva (×10)

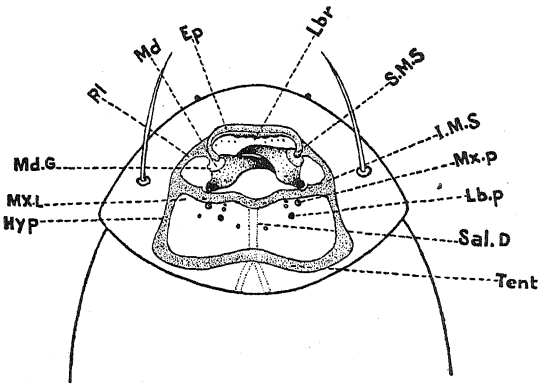
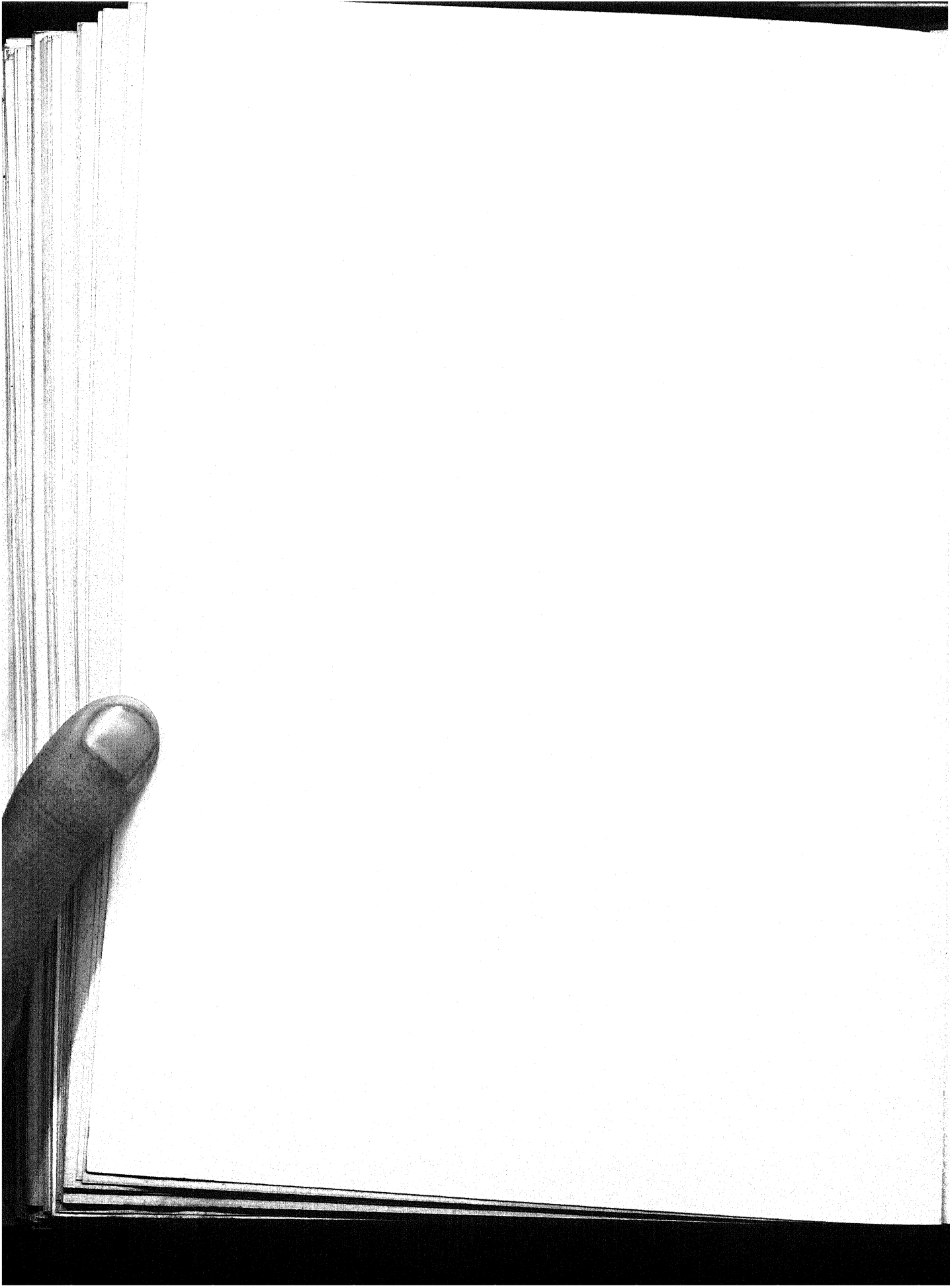


FIG. 5. Head and mouth-parts of full-grown larva



FIG. 6. Pupa (ventral view) (×12)

[Ep.=epistoma ; Hyp.=hypostoma ; I.M.S.=inferior mandibular strut ; Lbr.=labrum ; Pl.=pleurostoma ; S.M.S.=superior mandibular strut ; Md.=mandible ; Mxp.=maxillary palp ; Mdg.=Mandibular groove ; Lbp.=labial palp ; Tent.=tentorium. Sal. d.=Salivary duct



latter species is comparatively of minor importance since it has been recorded only as a parasite of the Tettigoniid—*Metrioptera grisea* F. in Italy [Sarra, 1934]. The other species *E. vesicularis* is of considerable importance as a primary parasite of the Hessian fly, *Mayetiola destructor* (Say). This species is highly polyphagous parasitising as it does a great variety of insect hosts representing diverse insect orders. The distribution of the species, however, is limited to Europe and North America. According to Dr Ferriere *E. pedatoria* is the first known oriental species of the genus *Eupelmella*. He also adds that there is the possibility of some species described in *Eupelmus* Dalm. coming under this genus since the differences between the two genera *Eupelmus* and *Eupelmella* have not been fully recognised. It is further pointed out that this Indian species is specially related to the European *E. mullneri* Ruschka, and the North African *E. schyzomyiae* Masi.

Distribution

So far as the present studies go, its distribution is confined to Coimbatore and surroundings. Further investigations may very likely disclose its presence in other localities in South India.

Hosts

The host range of the species appears to be restricted to Coleoptera and Hymenoptera so far as the writer's limited observations go. In nature, the species has been found to parasitise the full-grown grubs of *Pempheres* infesting Cambodia variety of cotton. Occasionally earlier stage grubs are also oviposited upon. It has also been reared from eggs and early instars of *Hypolixus* grubs boring into stems of amaranthus. There is a single representative of the species which has been reared by Mr V. Margabandhu from *Apion* grubs boring into a common weed, *Corchorus trilocularis*, found growing in and near cotton fields. In considering the host range it is of interest to note that the species ordinarily exists as a primary parasite, but in some cases can take up the role of a secondary or hyperparasite. In the course of the present studies it has been actually recovered as a hyperparasite from cotton fields on two occasions. First, on August 17, 1937, a newly hatched larva was taken feeding externally on a mature Eulophid larva—*Euderus pempheriphila* (Ramakrishna and Mani)—which is a primary parasite of *Pempheres* grubs. The parasite was again collected on the 24th of the same month as a small larva feeding on *Euderus* pupa. In laboratory trials it was found that no hosts other than *Pempheres* grubs were accepted for oviposition. *Hypolixus* grubs, *Euderus* larvae and pupae and various stages of other parasites, like *Dinarmus coimbatorensis* Ferr., etc. were supplied in cotton stalks and capsules for oviposition trials but with negative results. As seen in nature and from its ready acceptance of *Pempheres* in cages for oviposition and development it may be inferred that the stem weevil is its natural and normal host in South India.

Breeding technique

Oviposition experiments were conducted in ordinary 6 in.×1 in. cotton plugged tubes with a daily supply of suitable host stages and food in the shape

of raisin or sugar or honey solution. The stages were safely lodged in artificial cells scooped out in fresh cotton stalks covered with a lid of thin bark and fastened by fine cotton threads. These stems were removed daily or as often as necessary and examined under a binocular. Development was studied in small gelatin capsules or paraffin cells into which parasitised stages were transferred to facilitate observations under a binocular. The rearing experiments were carried out in the laboratory at the Cotton Breeding Station during the period of July to December 1937. The temperature and humidity conditions of the period are graphically represented in Figs. 1-3.

Pre-oviposition period

The newly emerged adult female pays little or no attention to the host for about a minimum of seven days after emergence. During this period it either rests or feeds on the food supplies in the form of sugar solution or raisin and seldom interests itself in the loaded stalk supplied. This period was prolonged in some cases to a maximum of fourteen days as seen from the recorded data. The period averaged 9·5 days for six observed adults in the season August to December. A certain proportion of females was seen not to oviposit at all. Out of a series of twelve trials as many as six females, in spite of a prolonged life, failed to oviposit in laboratory trials, probably due to defective nourishment during their growing period.

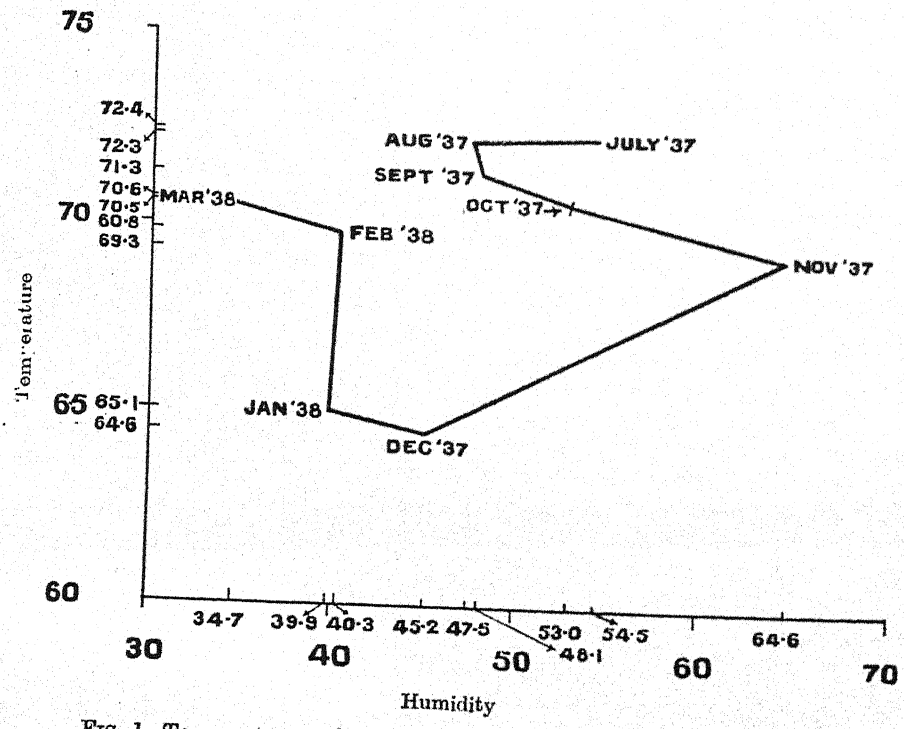


Fig. 1. Temperature and humidity curve 1937-38 (average minimum)

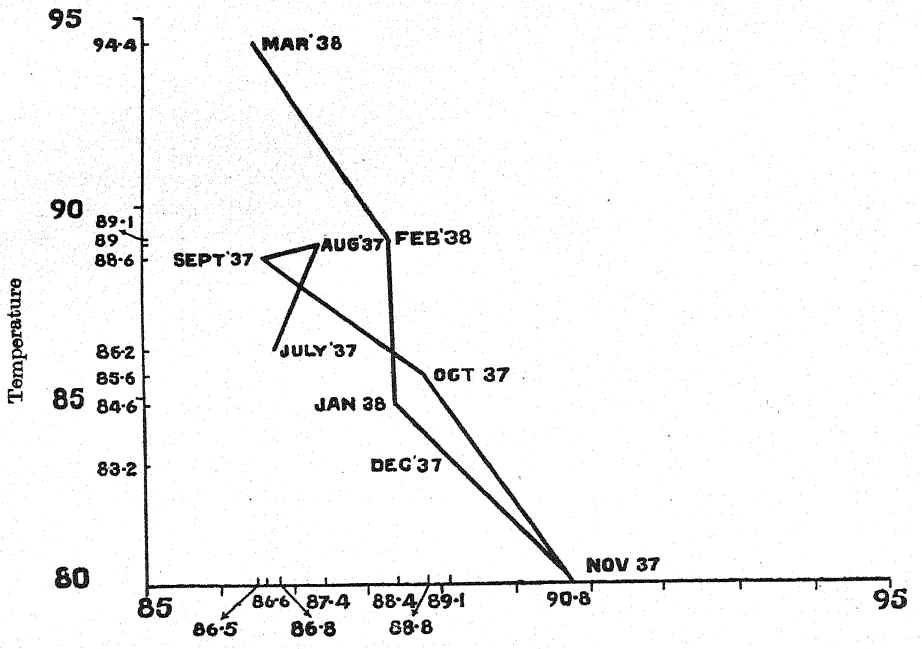


FIG. 2. Temperature and humidity curve, 1937-38 (average maximum)

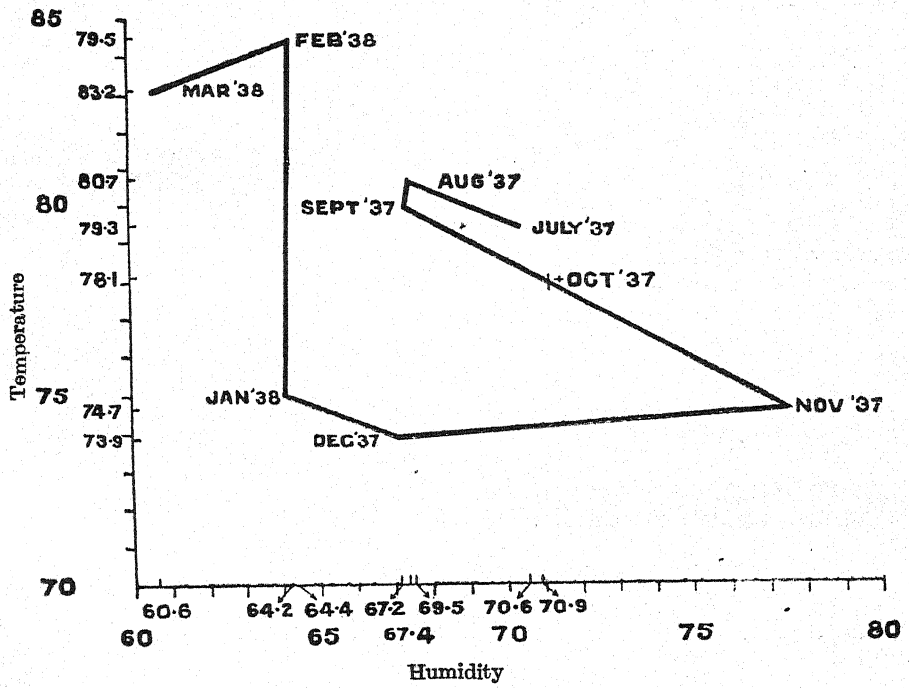


FIG. 3. Temperature and humidity curve, 1937-38 (average mean)

Oviposition

When ready to oviposit the female was seen to spend considerable time wandering slowly over the loaded stalk continuously testing it with its antennae, legs and tip of ovipositor. The antennae are seen directed forwards and downwards and are kept in constant vibration all the time. The parasite not infrequently strays away from the stalk only to return sooner or later to explore the same. After such scrutiny and apparently locating a mobile host grub inside the stem, the abdomen is lowered and the ovipositor is thrust through the bark or through the artificial slit in the stem and the same is driven deep to its entire length. Apparently an egg was laid and the parasite usually wandered away from the spot and no attempt at laying a second egg on the same spot was normally observed. The process of oviposition occupied only a few minutes. Generally oviposition takes place during the day and occasionally during nights. In captivity the parasites deposited normally one egg per host save in a solitary instance when two were placed in the same cell. The maximum per day also did not exceed this number.

Egg-laying period

The duration of the egg-laying period averaged 7·6 days with a maximum of sixteen days for six individuals observed. Oviposition was very irregular and at varying intervals extending up to a maximum of seven days. There was always a distinct post-oviposition period as may be seen from the data gathered. This period ranged from two to twenty-nine days averaging 12·3 days for six observed cases.

Condition of host and position of egg

While playing the part of a primary parasite, the host selected for oviposition was invariably a medium-sized or a full-grown *Pempheres* grub. In a series of trials with other stages, such as prepupae and pupae, no oviposition took place. In the case of *Hypolixus* host, the earlier instar grubs were seen to be preferred in nature. The size of the host apparently forms an important criterion in its choice. The host grubs are seldom noted to be completely paralysed. In almost all cases the host was rendered only partially inactive by stinging, and in consequence the egg deposited may often be found dislodged in the host tunnel. Normally the eggs are placed loosely without any sort of attachment on any part of the host body. Not infrequently these are found deposited in the host tunnel amid excreta and frass. In such cases the larva on hatching moves about quickly in search of the host which it may or may not encounter in the vicinity. A small proportion of host stages was merely partially paralysed without any deposition of eggs. As many as thirty-four stages were rendered partially inactive by a lot of ten females unaccompanied by actual oviposition. It works up to an average of 3·3 stages per female.

Egg (*Plate XXXV, fig. 2*).—The dimensions of the egg vary greatly in accordance with the size of the ovipositing adult. It varies in length from 0·40 mm. to 0·47 mm. averaging 0·45 mm. for five eggs and in width from 0·11 mm. to 0·275 mm. averaging 0·18 mm. The eggs are white in colour with a shining, smooth, polished surface. They are stalked and ellipsoidal in

form with two processes at the poles—a large tubular hollow pedicel at cephalic end measuring 0·35 mm., i.e. approximately two-thirds of the length of the egg and a thin hair like flagellum often irregularly bent or twisted at the caudal end measuring 0·18 mm. roughly equal to the width of the egg. The pedicel is usually folded back along the sides of the egg but may be bent or twisted slightly in various ways.

Incubation

The incubation period ranged from a minimum of one day to a maximum of two days averaging thirty-nine hours for ten eggs during the season July to November 1937. There occurs no appreciable change in colour before hatching except that the thin chorion shrinks to some extent. Prior to hatching the dark brown curved sharp mandibles of the embryo work at the cephalic end near the base of the pedicel. In about ten minutes a breach is effected in the chorion through which the larval head is protruded. The larva emerges slowly taking about forty-five minutes to one hour for completing the process.

Immature stages

1st stage larva (*Plate XXXV, fig. 3*).—The newly hatched larva is translucent white and somewhat flattened and spindle shaped. It is widest in the middle, tapering acutely at the abdominal tip. The head has a slight tinge of yellow and is more chitinised. It is convex in shape and bluntly pointed anteriorly. It bears a pair of minute distinct antenae. The mandibles are dark brown, sickle shaped and strong. Length varies from 0·51 mm. to 0·76 mm. averaging 0·62 mm. for five individuals; the width varies from 0·15 mm. to 0·33 mm. averaging 0·22 mm.; the width of the head averages 0·19 mm. The head is followed by thirteen well-delineated segments with long sensory hairs. The latter are arranged in two rows—dorso-lateral and lateral rows on either side of the median line. The hairs, particularly the lateral ones, on the first two segments are the longest, being nearly $2\frac{1}{2}$ times as long as the rest. The primary larvae are often hatched at a distance from hosts and have to wander about in their search. Not infrequently the host grub itself being only partially paralysed may have migrated in the stem to a distance. In spite of the active search, some larvae might fail to reach the host and perish. The moment it approaches a host, it takes a strong hold on the cuticle by its sharp curved mandibles and begins to imbibe food by energetic suction. The host grub wriggles violently and tries to dislodge the parasite but the latter persists in clinging to its hold. In a few moments the host is rendered helpless and passive, probably by the injection of a toxin by the bite of the parasite. The parasite continues feeding vigorously and the stomach is seen coloured by its contents. The first moult of the larva has been observed in a few cases and takes place within about sixteen hours after hatching.

2nd stage larva.—The larva is glassy white in this stage except for the cream-coloured stomach. It is less flattened and more rounded in form save at the head. The sensorial hairs are much shorter and less conspicuous. These hairs are all of equal length. Average length 1·10 mm.; average width 0·41 mm. and head 0·26 mm.

3rd stage larva.—This stage is more or less similar to the previous one except in size. The mandibles are straight and pointed. Average length 1·65 mm., average width 0·50 mm. and head 0·30 mm.

4th stage larva.—The general aspect is seen to be slightly changed at this stage. The head has become more chitinised and brownish. The mandibles have approximately become triangular. The body is shorter and has become dirty white in colour. It is less active and makes wriggling movements anchored on its head. Average length 2·3 mm., average width 0·65 mm. and head 0·40 mm.

5th stage or full-grown larva (*Plate XXXV, fig. 4*).—This stage is distinctly different in form and colour from the preceding ones.

Length varied from 3·52 mm. to 4·75 mm. averaging 4·03 mm.

Width varied from 0·90 mm. to 1·43 mm. averaging 1·22 mm.

Head varied from 0·42 mm. to 0·74 mm. averaging 0·53 mm. for four larvae.

The general colour has turned to dirty grey. The form has become more rounded and stout in the middle with tapering extremities. Head (Plate XXXV, fig. 5) is convex and short having a pair of cylindrical unjointed antennae and four long setae. The mandibles are dark brown, heavily chitinised and triangular with upper and lower articular processes. The labrum is heavily chitinised in the centre and is coloured dark brown bearing four to seven teeth-like denticles on its ventral aspect. The maxillae are transparent and inconspicuous bearing a pair of tubercles representing maxillary palps. The labium is also thin and possesses a pair of palp-like projections. The body segmentations are distinct having seven longitudinal rows of long setae along dorsal and lateral aspects. Two of these rows are incomplete and extend only till sixth segment. The spiracles numbering nine are open and clear at this stage. The larva, in general, is dull and sluggish.

Larval life after hatching.—The newly hatched larva makes rapid movements in a looping manner by using its mandibles and abdominal tip. It often stands anchored on its head with the rest of the body being raised and swayed in the air in a circle. In about two days the host-grub is killed. By the time it gets full grown nothing remains of the host except its hard head capsule and empty collapsed cuticle. It moves away from the host-remains and enters the prepupal stage. Never more than one adult developed from a single host even though two or more eggs or larvae were artificially left on the same host The developing adults from ill-fed larvae are all under-sized and seldom oviposit. The larval period varied from five to fourteen days averaging 8·3 days for nine individuals.

Prepupa.—The full-grown larva, after voiding the meconium in the form of a small heap of brownish pellets at the caudal end, enters the prepupal stage. The prepupa is ivory white in colour and is contracted very much in size. The size varied within a wide range but averaged 3·6 mm. in length and 1·30 mm. in width for four individuals. It is capable of slight movements when disturbed. It is seen slightly wrinkled and folded in the thoracic region. The duration of this stage varied from one to three days averaging two days for eleven individuals after the discharge of the last meconial pellet.

Pupa (*Plate XXXV, fig. 6*).—The newly formed pupa is yellowish white. It becomes light brown on the second day and turns deep leathery brown in about two days. Soon after, the eyes and antennae become darkened and still later the entire head and thorax turn dark. Gradually the rest of the body also assumes this colour. It is in shape slightly convex on the dorsal surface with the head slightly broader than the body. The size varied greatly but averaged 3·27 mm. in length and 1·1 mm. in width for four individuals. The duration of the pupal period varied from six to twenty days averaging 10·4 days for ten individuals during the season July 1937 to March 1938.

Emergence of the adult.—The pupal covering of the head region breaks transversely at the neck region and the same is pushed forward as a cap to begin with. The rest of the pupal skin splits along the sides from the thorax as far as the middle of the abdomen, dividing it into dorsal and ventral halves. The shining bluish dark adult emerges by pushing itself forward leaving the empty pupal skin behind. The entire process of emergence occupies about twenty to thirty minutes. Ultimately it emerges from the host tunnel to the outer world by gnawing a minute aperture through the bark.

Life-cycle and seasonal history

Since July 1937 when it was first discovered as a parasite of *Pempheres*, laboratory rearings have been conducted till the end of the year. The species has been again met with in February-March 1938 in small numbers in the seasonal crop. Full details on the duration of the total life-cycle periods of a few are furnished in the following table. Data on the rearings of other specimens have been omitted since the records are incomplete in some respects.

Incubation period (days)	Larval period (days)	Prepupal period (days)	Pupal period (days)	Total life-cycle (days)	Sex
2	7	1	7	17	Female
2	5	1	11	19	,,
2	9	3	9	23	,,
1	8	1	11	21	,,
1½	8	2	12	23½	,,

The total life-cycle period got prolonged from seventeen days in July to 23½ days in November and averaged 20·7 days during the period for five individuals. With the approach of the cold season when the temperature goes down accompanied by a comparative rise in humidity, the duration of the developmental instars is found to be prolonged. The duration of the life-cycle period was found to be shortened to some extent (occupying roughly 16½ days) when the species functioned as a secondary parasite on Eulophid pupa. As a primary parasite on the other host, *Hypolixus* grubs, the life-cycle covered

roughly 17½ days. The life-cycle period is seen to be still further shortened when it parasitises *Hypolixus* eggs. Roughly it is seen to cover fourteen to fifteen days with one or two days as egg, five or six days as larva and six to seven days as prepupa and pupa. Even though the data available are admittedly meagre it may be concluded that the period shows appreciable variation not only with the season but also according to the nature of the hosts on which the parasites develop. Considering the period occupied by the host for completing one generation, it may be evident that the parasite can easily have two to three generations for one of the host. Further, since the host generations are uneven and overlapping, the parasite has chance to breed continuously.

Hyperparasitism

The species is usually a primary parasite and its typical or normal host appears to be *Pempheres* grubs. It has been also noted to parasitise occasionally a few other stem-boring weevils. Its activities are not always an unmixed blessing since it has been also definitely noted to play the part of a secondary at times. On two occasions it has been actually taken as a hyperparasite on larva and pupa of the Eulophid—*Euderus pempheriphila*—which is an ectophagous primary parasite of *Pempheres*. It is not possible to say whether the parasite shows any distinct preference to weevil grubs. There is considerable justification in concluding that the species may assume the role of a secondary probably on occasions when primaries occur in abundance and become easily accessible.

Habits of the adult parasite

McConnell [1918] has recorded that an allied species *E. vesicularis* is fond of feeding on the body fluids of the host from the punctures made during oviposition. The writer, despite continuous and careful observations, has not seen this phenomenon in this species. The habit of stinging and paralysing a number of host grubs unaccompanied by egg deposition lends support to the idea that it attacks these probably for purposes of feeding. This diet, however, is not apparently essential for reproduction of the species. The parasite feeds with considerable relish on sweet liquids or raisin and its longevity is considerably increased by this diet. The parasite is very active though devoid of functional wings. They can run rapidly in cages and can take sudden and long leaps in quick succession. The hind limbs and the general build of the parasite are considerably adapted for easy performance of this function. The species is distinctly phototropic and always travels by leaps away from the shaded portions of cages.

Longevity

In the course of the breeding trials some data have been secured. The longevity ranged from a minimum of six days to a maximum of forty-seven days averaging 19·7 days for twelve individuals. It may also be seen that their life is considerably prolonged in the cooler months of October, November and December.

Thelyotoky

The reproduction of the species is characterised by thelyotokous parthenogenesis. From field collections the parasite has been recovered in various developmental stages and these have invariably developed into adults of female sex only. Very nearly three generations of the species have been reared in the laboratory without the appearance of a single male. It looks as if males are unknown in the species ; probably they do not exist ; and that reproduction is always thelyotokous. A proportion among the progeny was found to be incapable of oviposition but this may be due to defective nourishment in the early instars.

Thelyotokous reproduction has been noted in a few instances in parasitic Hymenoptera. Vance [1931] found it to be of common occurrence in *Apanteles thompsoni* Lyle. *Dinocampus terminatus* Nees is another Braconid that reproduces in the same manner. A few other species where the phenomenon is common have been recorded. A great majority of such species belong to Chalcidoidea. Among these may be mentioned *Thripoctenus russelli* Crawford—an internal parasite of thrips, *Achrysopophagus modestus* Timberlake, *Coccophagus modestus* Silv., an Aphid parasite *Aphelinus jucundus* Gahan and the allied species *Eupelmella vesicularis* Retz. a parasite of the Hessian fly. A few, namely, *Hemiteles longicauda* Thoms, *Hemiteles tenellus* Say, *Nemeritis canescens* Gravenh, come under Ichneumonidae. Doner [1936] has recorded two species of parasites of *Coleophora pruniella* which are thelyotokous, namely *Hemiteles tenellus* and *Eupelmella vesicularis*.

Apparently this method of reproduction is of considerable advantage to the species for its rapid multiplication. Reproduction has not got to depend on chances of mating with males. The entire progeny being females, the species has the potentiality of a rapid increase in numbers within a few generations. So far as the present brief studies go, this species has not been observed to be much affected by the apparent advantages of thelyotoky. There has been no great rapidity in its multiplication, very probably brought about by defective nourishment in the feeding instars in rearings in captivity.

Economic importance

The evaluation of the action of a parasite is extremely difficult and requires a great deal of careful and prolonged investigation. The parasite has been encountered only quite recently and its economic possibilities have not been sufficiently explored. These have not occurred in such numbers in the fields as to be of any great significance in the control of the pest. It is a primary parasite which can multiply by thelyotoky. It destroys more hosts than actually oviposited upon. These qualities certainly make for efficiency. On the other hand, their poor rate of oviposition, comparatively prolonged life-cycle period in certain seasons and tendency to play the role of a hyperparasite greatly detract from its economic value. The parasite, however, is of considerable scientific importance because of its unique distribution and polyphagous instincts.

Acknowledgements

The writer is indebted to Sir Guy A. K. Marshall, Director, the Imperial Institute of Entomology, London, and Dr Ferriere for the identification of

the parasite. The author has to express his gratitude to the Indian Central Cotton Committee for affording financial assistance and to the Cotton Specialist for the facilities provided. The writer wishes to record his thanks to his colleagues for help in making the field collections.

REFERENCES

Bridwell, J. C. and Bottimer, L. J. (1933). *J. Agric. Res.* **46**, 739-51
Cockerell, T. D. A. (1929). *J. Econ. Ent.* **22**, 985
Dalman. K. (1820)*. *Svenska Vetenska-Akad-Handl.* **41**, 379
De Geer (1771)*. *Mem. Servia a l'histoire des Insectes*, **5**, 2, 909
Doner, M. H. (1936). *Ann. Ent. Soc. Amer.* **29**, 229
Ferriere, Ch. (1939). *Bull. Ent. Res.* **31**, 165
Gahan, A. B. (1933). *U. S. Dept. Agric. Misc. Pub.* (*Washington*) **174**
Hill, C. C. and Smith, H. D. (1928). *J. Agric. Res.* **36**, 153
Jancke, O. (1934)*. *Nachr. BL. Disch. Pflsch. Dienst.* **14**, 45
Lindeman, K. (1887)*. *Bull. Soc. Imp. Nat. Moscou* (*n. s.*) **1**, 190
List, M. (1932).* *Bull. Colorado Expt. Sta.* **385**
Masi, A. (1919)*. *Ann. Mus. Civ. Stor. Nat. Genova* (3) **8**, 309
McConnell, W. R. (1918). *J. Econ. Ent.* **11**. 168-75
Morris, K. R. S. and Cameron, E. (1935). *Bull. Ent. Res.* **26**, 407
Muesebeck, C. F. W. and Dohanian, S. M. (1927)*. *U. S. Dept. Agric. Bull.* **1487**
Phyllips, W. J. (1927). *J. Agric. Res.* **34**, 751
Phyllips, W. J. and Poos, F. W. (1927)*. *J. Agric. Res.* **34**, 473-82
Retzius, M. (1783)*. *Genera et species insectorum*, **70**
Rockwood, L. P. and Reeher, M. M. (1933). *U. S. Dept. Agric. Tech. Bull.* **361**
Salt, G. (1931). *Bull. Ent. Res.* **22**, 482
Sarra, R. (1934). *Bull. Lab. Zool. Portici* **28**, 197-209
Scheidter, F. (1934)*. *Pflanzenkrankheiten* **44**, 369
Sovenson, C. J. (1935)*. *Proc. Utah Acad. Sci.* **11**, 249
Vance, A. M. (1931). *U. S. Dept. Agric. Tech. Bull.* **233**
————(1935). *Bull. Utah. Agric. Expt. Sta.* **250**

* Not seen in the original

THE ANATOMY, LIFE AND SEASONAL HISTORIES OF STRIPED MOTH-BORERS OF SUGARCANE IN NORTH BIHAR AND WEST UNITED PROVINCES

BY

B. D. GUPTA, M.Sc., Assoc. I. A. R. I.

Cane Entomologist, Sugarcane Research Station, Muzaffarnagar, United Provinces

(Received for publication on 24 February 1938)

(With Plates XXXVI and XXXVII and five text-figures)

Introduction

A GOOD deal of confusion prevails in the identification of moth borers of sugarcane, viz. :—

1. *Argyria sticticraspis* Hmpsn.
2. *Diatraea auricilia* Ddgn.
3. *Diatraea venosata* Wlk.
4. *Chilo zonellus* Swinh.

The larvæ, pupæ and moths are so similar in their general colouration that it becomes difficult to say which is which. The larvæ possess four to five violet stripes with dark grey tubercles studded over them. These tubercles change their colour due to seasonal and sexual dimorphism which makes their identification still more difficult. For this reason it is desirable to have full descriptions of adults, pupæ and larvæ along with their habits and life histories which will render the identification easier. The description of *Argyria tumidicostalis* Hmpsn., the striped borer of Bengal, has been left out as the author did not come across this borer either in North Bihar or in West United Provinces.

Historical

Mukerji [1857] described the borer as '*dhosah*' from Bengal. Cotes [1889] named it *Diatraea saccharalis* Fabr. Hampson [1898] merged it erroneously with the sorghum borer which he determined as *Chilo simplex* Butler. It was Maxwell Lefroy [1906] who indicated that the said species was different from *Chilo simplex* and named it as *Diatraea auricilia* Ddgn. He asserted that *Diatraea saccharalis* Fabr. did not occur in India. Its true position was brought to light in 1926 when T. Bainbrigge Fletcher compared the Indian species of *Diatraea auricilia* (*Proceeding III Ent. Meeting*, Vol. I, p. 387, pl. 48 and 49, fig. 1) with Dudgeon's *Diatraea auricilia* in the British Museum and established that it was *Argyria sticticraspis* Hmpsn. At the same time the name *Chilo simplex* Butler was discarded in favour of *Chilo zonellus* Swinh. This information indicates that the moth borer sketched by Cotes [1889] in *Indian Museum Notes* Vol. 1, No. 1, pl. 2, figs. 2 (a & b) and named as *Diatraea saccharalis* Fabr. was really *Argyria sticticraspis* Hmpsn.

In some of the recent publications the generic name of *sticticraspis* Hmpsn. has been changed from *Argyria* to *Diatræa*. The matter was enquired from the Imperial Institute of Entomology, London. Sir Guy A. K. Marshall's remarks of 28 July 1938 on the present position of *Argyria* are quoted :—

> 'In the British Museum collection this insect stands under the genus *Argyria*, but there is a note added to the series to the effect that the species really belongs to the genus *Diatraea*. This note was put in the collection by Mr T. Bainbrigge Fletcher, and it is as a result of this note that we have sent out the species under *Diatraea*. I have now consulted Mr Tams on the subject and he informs me that he does not agree with Mr Fletcher's opinion. Unfortunately the genus *Argyria* as constituted by Hampson is in very great confusion, and an extensive revision will be necessary before the species which really belong to it can be ascertained. For the present, however, Mr Tams suggests that *sticticraspis* should be retained in the genus *Argyria*'.

Occurrence and distribution

Argyria sticticraspis Hmpsn. occurs in sugarcane during the hot weather of April, May and June when the crop is young. Its activity goes down with the breaking of monsoon rains. The borer is fond of shoots and has not been observed to do severe damage to cane stalks in these parts. *Diatraea auricilia* Ddgn. and *Diatraea venosata* Wlk. attack the grown-up canes during rains and continue their ravages till hibernation sets in in November. *Chilo zonellus* Swinh. is not really a pest of sugarcane. It has been found to occur in only those cane fields which are in the neighbourhood of borer-infested fields of maize (*Zea Mays*) or *juar* (*Andropogon sorghum*). In all these cases the borer injury can be detected by the drying up of the central leaf sheath commonly known as ' dead heart '.

Cultivators do not differentiate between different species of borers but designate them according to their colour, habits or the effects they produce on the crop. They are locally known as *goruan* in the Punjab, *dhosah* and *majeru* in Bengal, *phankala*, *kansua* and *pihka* in the United Provinces. These names in the languages of the provinces indicate that some of these borer species are present practically all over the sugarcane tract of northern India.

Morphology

(1) *Argyria sticticraspis* Hmpsn.

Adult

Female—Wing expanse 23 to 35 mm., colouration of female as given by Hampson [1919] is noted below :—

> 'Head and thorax greyish ochraceous suffused with red brown ; palpi irrorated with dark-brown ; abdomen greyish ochreous with rufous at base of dorsum ; pectus, legs and ventral surface of abdomen tinged white with ochreous brown. Fore-wings greyish ochreous suffused with red brown. The cell and area just below and beyond it irrorated with darker red brown ; a curved post medial series

of small red brown spots in the inter-spaces from below costa to vein I ; a terminal series of minute black spots defined on inner side by slight white spots ; cilia with slight red brown lines near base and at middle. Hind wings pure white, underside of fore-wing tinged with rufous.

The females in the author's collection do not exactly agree with the description reproduced above. The post-medial series of brown spots is absent. In the inter-spaces from below costa to A_1 instead of these spots there is an ochreous streak without red-brown. Two dark spots between A_1 and Cu_1 behind the cell, another at the angle of the cell.

Male—Wing expanse from 19 to 26 mm. Head and thorax ochreous red brown ; antennæ ringed black and white, palpi ochreous mixed with dark brown. Tibiæ of 1st thoracic leg greyish ochreous, rest white red brown. Fore-wing pale red brown mixed with whitish and irrorated with blackish along the median nervure. Dark brown scales in front, behind and in the cell in the anterior median area. A black patch in front of the cell defined on outer side with a whitish spot. The area between marginal and submarginal dots dark brown with streaks as in the female. Hind wings ochreous ventrally in front of the cell.

Hampson did not describe the male of *Argyria sticticraspis* but has given the description of male of *Argyria coniarta*, a separate species, of which he did not describe the female. The description given above for the male of *Argyria sticticraspis* agrees with the male of *Argyria coniarta* Hmpsn. The description given by Hampson for the female of *Argyria sticticraspis* does not tally with the description of females in my collection. It thus appears that *Argyria sticticraspis* and *Argyria coniarta* are not two different species but have been separated on individual description of female in the former case and male in the latter of the same species.

Head.—Front convex in either sex. A well-defined epicranial suture between the two antennæ. Length of head shield greater than the breadth. Ocelli on protuberances behind the antennæ. Antennæ lamellate and flat in males and filiform in females. Scape large and swollen, pedical short and rounded, joints of funicle in male increase in width distally and shorten at the tip. Forty-one joints in both sexes. Internally every joint bears two big ciliated scales. Labrum is scaleless.

Thorax.—Patagia paired narrow transeverse plates closely opposed to the anterior end of the thorax. Well developed tegulæ covered with dense hairy scales. Prothoracic sclerite narrow, meso-scutum broad with a longtitudinal suture and meso-scutellum diamond shaped ; meta-scutum narrow in the middle and extended laterally with meta-scutellum extending far behind over the first abdominal segment.

Wing-venation (*Plate XXXVI, fig. 1*).—Fore-wing : (Nomenclature after Comstock and Needham). Sc. well developed, separate and unbranched. R_1 from middle of the cell, R_2 and the stalk of R_3 and R_4 from before the angle of the cell. The stalk longer than either R_3 or R_4. R_5 from apex of the cell. M_1 is discocellular originating from the angle of the cell. Its point of origin nearer to R_5 than M_2. M_2 and M_3 arise from the cell in close proximity but are not fused. The cross vein PTV which closes the cell distally is fine but

prominent. It is curved inward to form an angle which is not sharply defined. The two branches of Cu_1 are present. Cu_2 absent. Cu_1a from before the lower angle of the cell and Cu_1b from the middle of the cell. A_1 is present but A_2 is rudimentary. R_4, R_5, M_1, M_2, M_3, Cu_1a, Cu_1b, and A_1 are equidistant with each other on the margin of the wing.

Hind wing: Sc. + R_1 and Rs. arising free but anastomosing closely beyond the cell to diverge again into Sc. + R_1 and Rs. M_1 from Rs. before its fusion with Sc. + R_1. The cross vein PTV is finer than that of the fore-wing and angle PTV is less than a right angle. The area of the cell is reduced due to drawing in of the cross-vein towards the base of the wing. M_2 and M_3 in a common stalk from the lower angle of the cell and diverge later into M_2 and M_3. Cu_1a from near the angle of the cell and Cu_1b from the middle of the cell. A_1, A_2, A_3 present. Frenulum consists of a single stout spine in males and of four spines in females.

Legs.—A pair of spurs on tibia of the first and second, and two pairs of spurs on the tibia of the third pairs of legs. Each leg has five tarsi, every joint of which bears a pair of spines. Claw is composed of paired ungus with pulvillus between. Ungus notched to give rise to a pair of spines.

Abdomen.—First abdominal segment is reduced being merged with that of meta-thorax ; sternum of second abdominal segment bears a pair of tympana. Segments 9th and 10th are modified to form genitalia in both the sexes.

Female genitalia (*terminology after Busck and Heinrich*).—Internal: They consist of ovaries, oviduct, collateral and accessory glands, their ducts and sperm-ducts. The ovaries consist of four ovarioles on each side extending from first to sixth abdominal segments. They are much convoluted in their course and fill the whole of the abdomen in freshly emerged specimens. Oviduct is formed by the two groups of four ovarioles from each side to open on the ovipositer. Collateral gland is of a small size and communicates with the oviduct. Below, the oviduct receives the sperm-duct from ductus bursæ. The sperm-duct joins the oviduct on the ventral surface near the junction of the collateral gland. Receptacula seminalis lies above the angle of the junction of ovarioles. A pair of accessory glands milk-white in colour and full of chalky material open into the oviduct in the ninth abdominal segment. The two glands communicate with each other below the rectum.

External: Ovipositor is a chitinous oval ring profusely studded with setæ and bristles. The ring is supported by chitinous stylets. The genital opening or the opening of bursa copulatrixlies on the ventral surface of the eighth abdominal segment on a heavily chitinised plate. Bursa copulatrix is provided with a star-shaped crystal—the signum.

Male genitalia.—Internal: Testes are in the form of a single dorso-ventrally flattened, round disc of a light yellowish green colour. Two vasa-deferentia (v. d.) arise posteriorly and after a short distance enlarge into two pearl-shaped pouches—the vesicula seminalis (v. s.) afterwards getting narrower to open into the accessory glands. The latter are paired tubes closely approximated together and are full of chalk-like material. They get considerably prolonged anteriorly in a thread-like form. Posteriorly they unite to form the ejaculatory duct which opens on the adeagus after a much convoluted course.

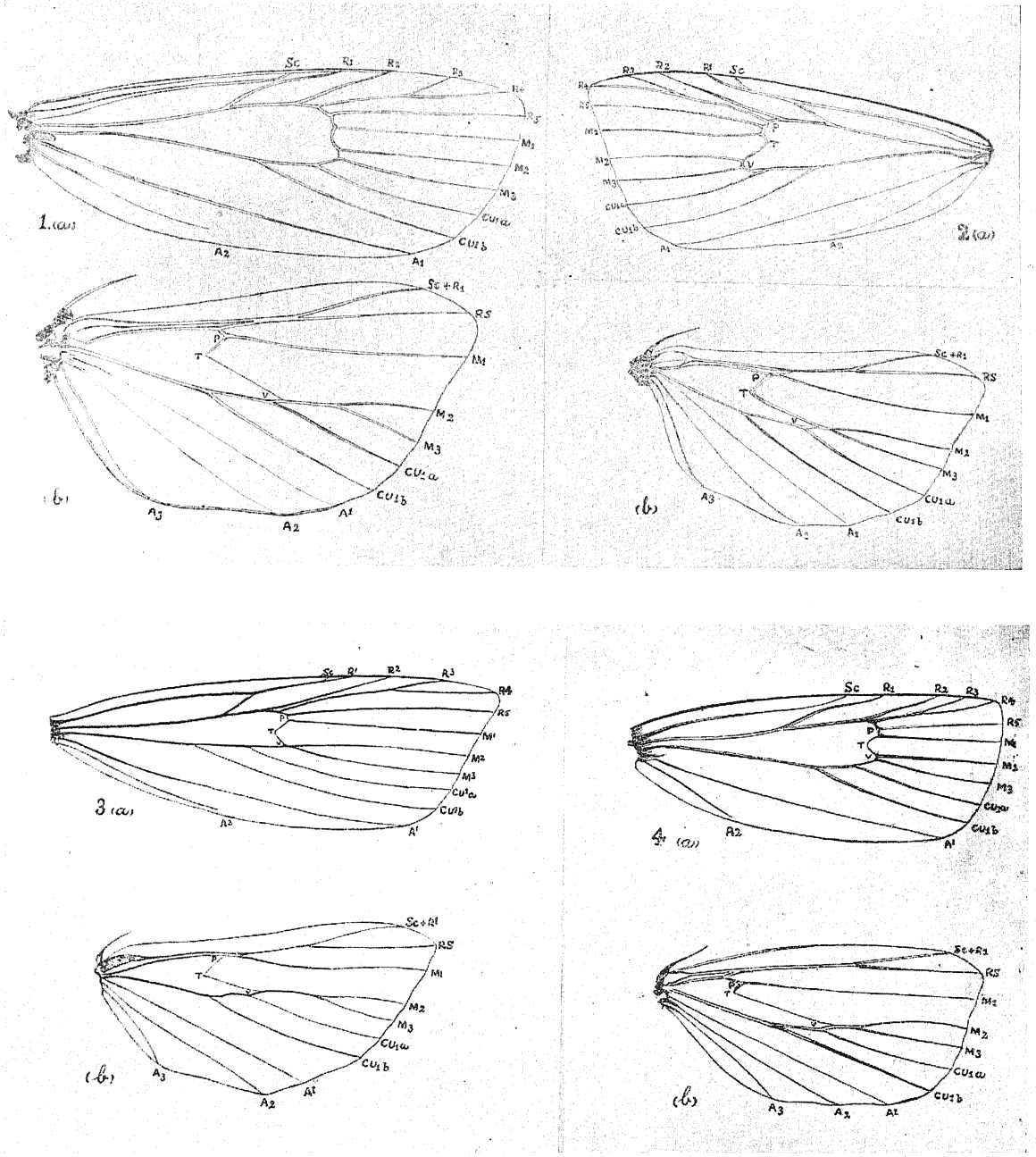


FIG. 1 (*a*) & (*b*) Wing-venation of *Argyria sticticraspis*
FIG. 2 (*a*) & (*b*) ,, ,, of *Diatraea auricilia*
FIG. 3 (*a*) & (*b*) ,, ,, of *Diatraea venosata*
FIG. 4 (*a*) & (*b*) ,, ,, of *Chilo zonellus*

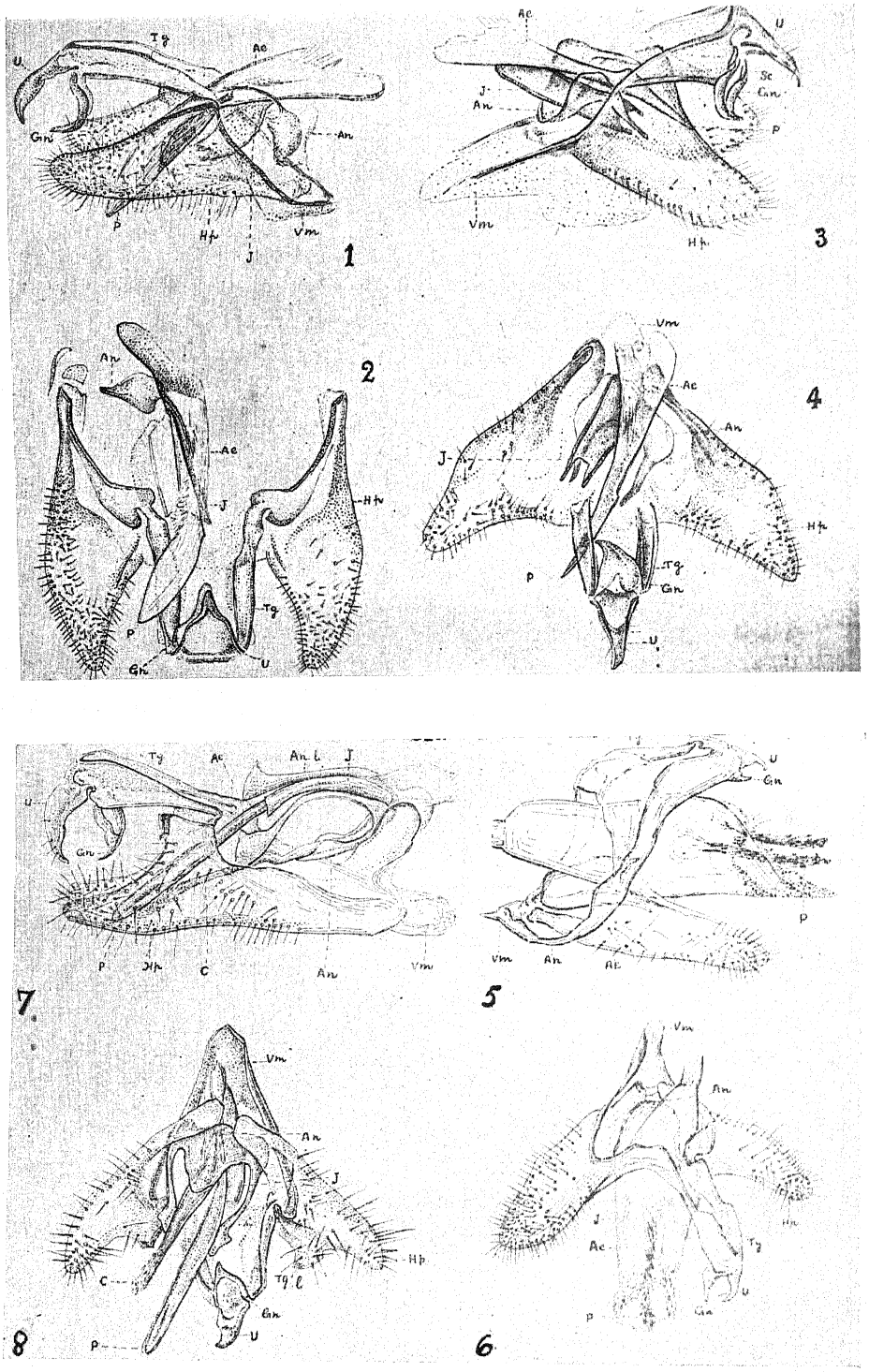


FIG. 1 & 2. External male genitalia of *Argyria stictieraspis*
FIG. 3 & 4. ,, ,, ,, of *Diatraea auricilia*
FIG. 5 & 6. ,, ,, ,, of *Diatraea venosata*
FIG. 7 & 8. ,, ,, ,, of *Chilo zonellus*

External (Plate, XXXVII, figs. 1 & 2): Vinculum (vm) flat, heavily chitinised and enlarged ventrally. Anellus surrounds the adeagus partially. Juxta bilobed and closely applied to adeagus ventrally. It is canaliculus. Adeagus slightly bent with blind sac produced posteriorly beyond the entrance of ductus ejaculatorious. Penis curved and sword shaped with cornutii present. Harpes hinged within the vinculum, simple wing-like, triangular and divided but without any basal lobes. Tegumen broad at the place of articulation with gnathos. Uncus single, massive and triangular. Gnathos hook-like forming achæla with uncus.

PUPA

Elongated, slender from deep to dark brown in colour, measuring approximately 13 mm. in males and 17 mm. in females. The integument is transparent in newly formed pupæ and development of the imago can be observed.

Head.—Pair of frontal setæ on fronto-clypeal region which is flat ventrally. Pilifers and maxillary palpi present. Eyes promixally sculptured and distally glazed; large in males than in females. Labrum well differentiated with a prominent notch. Front laterally extended into projections over the eyes.

Thorax.—Mid-dorsal ridge extending from prothoracic to meta-thoracic terga. Pronotum narrow and rough with a spine on each side of the ridge. Mesonotum very wide; mesoscutellum not differentiated. Wings extend beyond the ventral half of the fourth abdominal segment. Wing suture is not defined on the mesonotum. Anteriorly the margin is raised in the form of a semi-lunar curve which possesses a metallic lustre. Mesothoracic legs do not reach the ventral margin of the wings. Meta-thoracic appendages extend beyond the wings.

Abdomen.—First four abdominal segments are free dorsally while hidden below by the integument of the wings. A pair of setæ of the anterior trapezoid warts persist on all the abdominal segments as short brown spines. First pair of abdominal spiracles absent; present on second to seventh abdominal segments on raised projections. Eighth abdominal spiracle atrophied but its situation visible. Ventrally the impression of the prolegs is left on the fifth and sixth abdominal segments. Dorsal surface of fifth, sixth and seventh segments bear ridges. They lie in the anterior half of each segment between the lateral spiracles of the two sides. They encircle the seventh abdominal segment and their sharp projections are directed backward. The dorsal half of the tenth abdominal segment possesses four spines directed towards the posterior.

Genital openings.—The male genital opening lies on the sternum of the ninth abdominal segment. It is in the form of a fine slit lying between two raised projections. The female genital opening lies ventrally on the eighth abdominal segment in the form of a narrow longitudinal dark brown slit.

LARVA

Full-grown larvæ measure 20 to 25 mm. in length and 4 mm. in breadth, cylindrical in shape with a dark brown head directed towards the anterior. The colour of the body is dirty white with five violet stripes on the dorsal surface. The stripes from second thoracic to eighth abdominal segment are arranged in the following manner (Fig. 1).

(1) Single dorsal stripe.
(2) The two sub-dorsals—one on each side of the dorsal stripe.
(3) The two laterals—one on each side of the sub-dorsals.

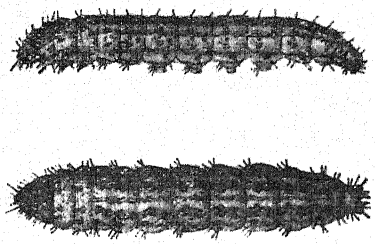


FIG. 1. Side and dorsal view of *Argyria sticticraspis* Hmpsn.

The dorsal stripe is central and unpaired and originates from the anterior border of the first abdominal segment and extends up to the tubercles on the eighth abdominal segment and often beyond it. It is straight and narrow and sometimes cannot be made out due to the brown colour of the alimentary canal lying below.

The sub-dorsals and lateral stripes originate from the meta-thoracic segment and join each other to encircle the eighth abdominal spiracle. The lateral stripes are supra-spiracular in position.

The body-wall is formed of transparent chitin studded over with dark grey tubercles bearing dark brown prominent setæ. The grey colour of the tubercles disappears in some of the mature larvæ before July and in all after July. With colourless tubercles and deep violet stripes the larvæ pass on to hibernate in winter.

Spiracles are oval in outline having a jet black rim with a clear space within. They are in nine pairs, viz. one on each side of first thoracic and others on the first to eighth abdominal segments. The last is the largest and more dorsally placed. The opening is guarded by several rows of filaments gradually increasing in size towards the interior. These ribbon-like filaments are provided with minute fibrillæ.

Larval details and chaetotaxy

The head is deep brown in colour becoming darker anteriorly. It is spherical in outline bulging in the posterior region and getting trapezoidal and dorso-ventrally flattened anteriorly which brings the mouth-parts on a level with the ground.

Head capsule.—Each epicranial plate bears six ocelli, four of which lie in an arc on the lateral margin while two are more ventrally situated. First ocellus is the largest while the third and fourth are smaller than others and lie approximated.

There are thirteen setæ and eight punctures besides the ultra-posterior group of setæ and punctures. Dyar and Heinrich [1927] nomenclature for setæ and punctures has been followed.

The anterior setæ A_1, A_2 and A_3 do not form exactly a right angle as they do in *Diatraea saccharalis* as described by Halloway and Loftin [1919], but lie

in an angle greater than a right angle. The distance between A_1 and A_2 is less than A_2 and A_3. Puncture Aa posterior to A_2 and in a line with A_1 and A_2. Posterior setæ P_1 and P_2 and puncture Pa parallel with the longitudinal ridge LR. P_1 in a line with adfrontal seta Adf_1 and Pa with the puncture Adfa, P_2 more approximated to Pa than P_1.

Ocellar setæ O_1, O_2 and O_3 are well separated. O_1 lies below and between the III and IV ocelli and is shortest of the group. O_2 biggest and nearer to ocellus I than VI. O_3 latero-posterad of ocellus VI with puncture Oa between ; Oa more approximated to ocellus VI than O_3. Punctures Ob and Oc lie anterior and approximated to ocelli IV and V respectively.

Sub-ocellar setæ So_1, So_2 and So_3 are situated ventrally in a triangular formation. So_1 in the ventral angle behind the antenna. So_2 approximated to ocelli V and VI. So_3 far removed, with puncture Soa between So_2 and So_3.

Lateral seta L_1 on the gena in a line with P_1. Puncture Pb between L_1 and P_1 but more approximated to L_1. Puncture La posterior to seta L_1. Genal puncture Ga and seta G_1 on ventral aspect in a line with cardo. The group of ultra-posterior setæ and puncture (x) lie posteriorly very much approximated to each other.

Frontal puncture Fa almost touching each other with frontal seta F_1 far behind situated latero-posteriorly. The frontal punctures are well separated in *Diatraea saccharalis*.

Adfrontal sclerites bear two minute setae and one puncture on each side. Distance between frontal seta F_1 to adfrontal seta Adf_1 is more than the distance between Adf_1 and Adf_2. Seta Adf_2 lies in the angle made by the adfrontal suture with the longitudinal ridge ; puncture Adfa nearer to Adf_2 than Adf_1. Cylpeus carries a pair of setæ E_1 and E_2 on each side. The third segment of antenna bears a shaft, a puncture, two spines and two sensory cones along with the articulation of fourth joint which carries one sensory cone of its own.

Mouth-parts.—Labrum : An unpaired oblong and flat sclerite with a little convexity in the central region, wider than high, free edges rounded and a notch in front. Two groups of setæ on each side of the notch. Median setæ M_1, M_2 and M_3 triangularly arranged. M_2 posterio-lateral and closer to M_1 than to M_3 which lies far in front. Lateral setæ, La_1, La_2 and La_3, lie in a curve one behind the other on the lateral margin. La_2 and M_3 on the same level. La_1, La_2 and La_3 equidistant with each other. Setæ La_2 longest of the group. Puncture Ma posterio-lateral to M_2 and lies behind in a line with M_1.

Epipharyngeal shield is closely applied to labrum above and possesses two sets of sensory cones. The first set ET lies in a triangular formation in the space below and between the median and lateral groups of setæ of the labrum. The other set consists of four sensory papillæ EP lying in a rectangular formation—two in front and two behind the seta M_2. Epipharyngeal rods are indicated by the posterior projections.

Mandibles : Each mandible bears six protuberances in the form of teeth—two of which are conical while others have a spherical or pointed appearance. Each mandible bears one small (*i*) and one large (*ii*) seta.

Labium : Ring shaped composed of three sclerites. First bears a pair of labial setæ, second forms a semi-circle at the base of the palp and carries three

pairs of punctures, two on each side of labial setæ and one on each side of the spinning tube. The third piece forms the spinnerat.

Maxillae : The maxillae are fused with the labium at the base but are free at the tip. Cardo forms the base. It is heavily chitinised and glove-shaped. Stipes bears two chitinised rings of the palpus having a spine on each with two lobes at the top. One is the maxillary palp and is two-jointed. The other is the maxilla proper ending in small sensory cones.

Mentum is triangular and lightly chitinised. It bears a pair of prominent setæ directed downwards and forwards. The paired sclerites lying one on each side of the mentum bounded by a part of stipes and cardo laterally constitute the submentum. It is formed by two triangular sclerites which are lightly chitinised and run with each other up to the posterior limits of the cardo.

Thorax.—Prothoracic shield covers dorsally the major portion of the first thoracic segment. It is broad and divided into two equal halves by a mid-dorsal longitudinal fissure. It is generally brown but gets dark on the approach of a moult and gets yellow when tubercles become colourless. Black pigment spots are present all over but they are more concentrated on the posterior border of the shield. It has seven setæ and three punctures named after Fracker [1915] on each half of the shield.

Anterior margin has three setæ Ia, Ib and Ic directed upwards and forward. Punctures X and Y adjacent to seta Ia and puncture Z approximate to Ib. The other group of setæ IIa, IIb and IIc are centrally placed. The posterior seta P is inconspicuous lying on the posterior periphery of the shield.

Sub-spiracular tubercle is formed by the fusion of the tubercles IV and V each having one seta. VI is bisetose, VII multisetose forming the base of the leg, VIII is unisetose and lies beyond the leg on the ventral surface. The segment is devoid of III tubercle.

Meso-and meta-thorax resemble each other in their arrangement of the setæ and punctures. Central dorsal tubercle CDT is bigger on the former than on the latter and corresponds with the prothoracic shield of the first thoracic segment. The two are devoid of setæ but possess brown pigment spots.

Ia and Ib of prothoracic shield form a separate tubercle lying anterio-lateral of CDT, similarly setæ IIa and IIb lie on a separate tubercle. III is unisetose, IV, V, VI, VII and VIII as on prothorax. Sometimes a small tubercle Va is present. When present it is often repeated on first four abdominal segments. Extra setæ Ixa, Ixb and Ixc lie in front of the leg on the ventral surface. The small tubercle Xa with a single seta lies on the anterior border in front of tubercle Ia and IIb. Bisetose tubercle Xcd is peculiar to these two segments and is not repeated on any other.

Thoracic leg.—Base is formed by VII tubercle with three prominent setæ in front, one behind and three facing the mid-ventral line. Leg has four segments. First has two setæ and two punctures second has a set of five to six spines, third has one dorsal and one ventral setæ while the fourth ends in a hooked claw.

Abdomen.—The tubercles Ia and Ib, IIa and IIb have become unisetose and lie one behind the other. Thus the four unisetose tubercles of the two sides lie in a trapezoid formation and are known as trapezoid tubercles. The bases of the setæ of the trapezoid tubercles lie at an angle of 50°. Anterior

trapezoid tubercles are spherical while the posterior ones are oval in outline. Two to three pigment spots are present anterior to seta I which is bigger than the seta II of the post-trapezoids. This trapezoidal arrangement is constant up to seventh abdominal segment. Often central dorsal tubercle CDT in-between the posterior trapezoid fuses with the latter on both sides. III is unisetose and supra-spiracular in position with a minute seta IIIa in proximity. In the segments following the first abdominal segment it gets separated from III and lies anterior to spiracle but fuses with III tubercle again on the eighth abdominal segment. IV and V are sub-spiracular and persist up to ninth abdominal segment. VI is unisetose throughout. VII is trisetose from first to sixth abdominal segments forming the leg plate on third, fourth, fifth and sixth abdominal segments, bisetose on seventh and unisetose afterwards. The only change that happens on the eighth abdominal segment is the fusion of the trapezoid tubercles. Tubercle I disappears on the ninth abdominal segment. III, IV and V fuse to form a bisetose tubercle. Tenth abdominal segment has an anal plate with four long setæ in each half. Pigment spots are present. Base of the clasper has eight setæ and one puncture. Ventral tubercle VIII is constant throughout.

Pseudo-leg.—It is a fleshy conical and retractile projection with round and flat apex directed towards the posterior. The sole is provided with a series of hooks called crochets. The hooks number about forty in adult caterpillars and are biordinal in arrangement. The spines are embedded in such a way that both the ends are free. They lie in a horse-shoe formation and open towards the exterior. The claspers on tenth abdominal segment are provided with crochets arranged in a semi-lunar curve.

THE EGG

The eggs are oval, dorso-ventrally flattened and are laid in clusters in three to five overlapping rows. Freshly laid eggs are transparent but become creamy white a few hours after deposition. An individual egg measures from 0·7 to 0·9 mm. in length and 0·65 mm. in breadth. All the eggs in an egg mass are of the same size and shape. The longitudinal axis is always parallel with the mid-rib of the leaf. They are firmly glued onto the surface of the leaf. The chorion is transparent, colourless and under a microscope reveals a beautiful ornamentation in the form of an irregular net-work of depressed lines. The empty egg-shells are white and more conspicuous and remain attached to the leaf till beaten away by weather.

The eggs are laid in clusters on the under-surface of the green leaf. They have never been seen on dried leaves. The egg-laying takes place at night. A single female laid 366 eggs in one night in eleven egg masses with sixteen to sixty-five eggs in each cluster. The oviposition was again resumed on the night following with five clusters having a total of 123 eggs. The number of eggs in the body is innumerable and dissection of females after egg-laying shows that all the eggs are not laid.

Unfertilized eggs are laid singly in scattered groups of two to three devoid of any symmetry. They quickly shrivel up. An unfertilised egg mass is seldom found in the field.

Development.—The originally homogeneous contents of the egg exhibit three well-defined bands twelve hours after oviposition. The developing larva lies in

the centre in a horse-shoe formation. The disintegration of yolk into small globules can be observed on the second day.

Two eye-spots and brown patches of future mandibles along with body segments appear on the third day. On the fourth day the head and prothorax become clear as dark bands, and tubercles with minute spines can be seen. Feeding on yolk can be marked by the movement of yolk strings towards the mouth where they are torn by the mandibles. Hatching takes place on the fourth to sixth morning at sunrise or at little after. Majority of the larvæ in the egg mass hatch out together. A few may take another twenty-four hours in hatching.

LIFE-HISTORY

Copulation generally occurs at night. A pair remained in copulation for 2½ hours in the laboratory. Eggs are laid a few hours after copulation. Incubation lasts from four to six days. Hatching always occurs at sunrise or a little later. Freshly hatched larvæ measure about 1·5 mm. with black head and prothorax. Body on hatching is dirty grey with faint impression of stripes. The abdominal trapezoid tubercles are present in the form of black dots.

Larvæ are quick and agile with very active spinning glands. They swing in the air by the silken threads and get dispersed to surrounding plants by the help of wind. They are quick in crawling from plant to plant or to the axils of leaves on the same plant. Those which come in contact with central whorl of plant leaves eat their way in and create dead heart. Later in the season when cane has formed they enter by making pin-holes anywhere in the internodes. In western United Province the young larvæ behave as leaf-miners for a few days before penetrating into the plant stalk.

Second instar larvæ.—Larval details get completed. Mid-dorsal stripe becomes continuous and prominent. Pro-legs assume their normal shape and crochets take the horse-shoe formation. Black pigment spots on tulercles are absent at this stage. They appear in the fourth instar. The larvæ get perfectly matured in the fifth instar.

Ecdysis.—When the time of moulting draws near, the caterpillar becomes motionless and stops feeding. The colour of the head and theprothoracic shield becomes black. The skin between the head and prothoracic region gets stretched and ultimately ruptures. By gradual contractions of the body this outer coat of skin is pushed back till it is cast off. The head capsule which is now an outer coat of the head is dashed against the surface and is gradually discarded by the help of the anterior pair of appendages.

Each moult takes about forty-five to sixty minutes. In the final moult the larva changes into a pupa. During the final moult, the head capsule is not cast off separately from the skin but the capsule ruptures along the epicranial suture and is discarded posteriorly along with the skin.

Five moults are common before the caterpillar actually pupates in the active season. The number of moults increases to seven or eight in hibernating larvæ.

The larvæ of *Diatræa saccharalis* eat their cast skins and are cannibalistic in habit as has been observed by Halloway and Loftin [1919]. I have not observed this phenomenon in the case of any of the sugarcane-borer larvæ.

Growth.—All the larvæ hatched from the same egg mass do not grow equally. The growth depends to some extent on the nature of food they come across. The larvæ fed on soft tissues grow more quickly than their fellows feeding on hard material. The larval existence is roundly of sixteen to twenty-one days' duration. Some larvæ take as many as thirty days to pupate. In case the plant succumbs to injuries and dries up, the larvæ, if not old enough, migrate to neighbouring plants and if full grown resort to pupation.

Pupal period.—This period considerably varies between the over-wintering larvæ and the larvæ of the active season. In February the period lasts from ten to twelve days, but in summer it is short and pupation is over within six to eight days, the average for the active season being a week. The progress of various pupal changes is as follows :—

1st day.—Body yellowish brown, stripes dirty-violet, rims of spiracles brown and projected, pro-legs atrophy rudiments of wings and appendages, two dark eye-spots and sexual markings are discernible.

2nd day.—Yellow colour deepens, venation is marked out, eye-spots turn into dark patches.

3rd day.—Compound eyes are differentiated.

5th day.—Pupa dark brown, eyes greenish grey, wing scales differentiated into black and white, gliding and rolling movement of posterior abdominal segments persists.

6th day.—Pupa deep dark brown, no sign of life exhibited.

7th day.—Emergence of chrysalis.

Emergence of adults.—This always occurs in the early hours of the morning generally before sunrise. Anterior extremity of pupa breaks to give exit to the moth. The first rupture is the transverse slit along the posterior border of the front. This piece breaks and hangs down. The second rupture is along the length of thorax in mid-dorsal region. The third slit is lateral and runs along the whole length of antennal suture of each side. During emergence the posterior pairs of legs are the first to be dragged out along with the thorax. In doing so first pair automatically comes out and is followed by the second pair of legs and wings. The latter are short and unexpanded. The body is held on first pair of appendages. After about twenty minutes the wings expand to cover the body and it is then that the 3rd pair of legs is brought to the ground.

Summary of life-cycle

The total period taken from egg-laying to the adult stage in laboratory cages is thirty days in September, viz. egg four to five days, larva twenty-one days and pupa seven days. The period of different instars of the larvæ hatched from the same egg mass is shown in Fig. 2. Twenty-seven days is the shortest period which an individual life-cycle takes from egg-laying to the emergence of adult.

SEASONAL HISTORY

Over-wintering larvæ are stimulated to activity by the last week of February when majority of them pupate. Emergence of moths begins by the beginning of March and continues for the whole of March and egg-laying continues till the middle of April. The adults of the second generation lay their eggs by the middle of May and moths continue to emerge till the end of June. The third

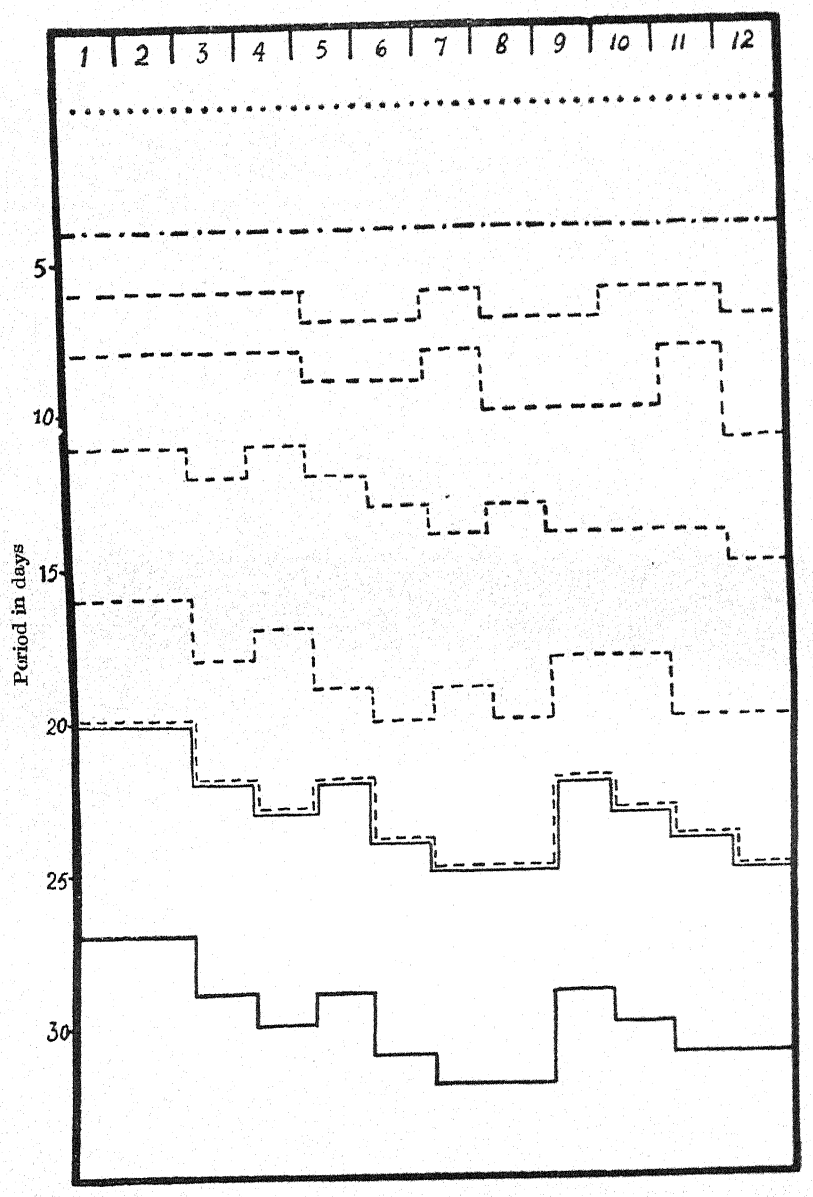


FIG. 2. Relative incubation period, duration of the larval stages and the pupal period of 12 *Argyria sticticraspis* all hatched from the same egg mass in September 1930

[.... Egg-laying; -.-.-. Hatching; - - - Instars; ═══ Pupation; ——— Emergence of chrysalis]

generation continues up to the middle of August and fourth finishes by the end of September. Egg-laying of fifth generation commences by the beginning of October and the larvæ hatched from these eggs hibernate. Thus there are five

to six generations in the year depending upon the early beginning of warm weather during spring and late closing of autumn for winter. This seasonal behaviour of the pest is true for both North Bihar and Western United Provinces.

(2) *Diatraea auricilia* Ddgn.

ADULT

Dudgeon [1905] described the adult from Pusa in the following words :—

'Antennæ of male flattened by coalescing lamellæ separated distinctly.

Males—Brown ochreous, irrorated with fuscous ; a raised metallic spot in the cell, another at the origin of vein 4 and 5, one above and one below vein 2. A few golden scales in and beyond the cell, a post-medial row of black dots incurved towards the costa with golden scales upon them, a marginal row of black dots. Cilia golden. Hind wing brownish white, cilia silvery.

Females—Big, antennæ simple, ground colour pale, ochreous with metallic spots smaller '.

The general colouration of the moth in my collection agrees with the description reproduced above. The maxillary and labial palpi ochreous but suffused with dark brown. Abdomen ochreous suffused with brown at the sides and beneath. Tibiæ of first thoracic appendage ochreous but irrorated with dark. There is a medial row of rufous lying at the distal border of the cell. Five metallic spots with golden scales in a regular curve over the rufous band. The raised metallic spot, as described by Dudgeon, lies at the apex of the cell at the origin of vein 6, i.e. M_1. Another spot along the rufous curve at the origin of R_2, R_3, R_4 and R_5. Ventrally the fore-wing is ochreous suffused with grey. Hind wing from ochreous to dark grey.

Antennæ in females are filiform with alternating grey and ochreous scales. Medial and sub-marginal rufous bands are imperceptible. Metallic spots arranged as in males.

On account of the golden lustre of the metallic spots and those of marginal cilia *Diatraea auricilia* Ddgn. is commonly known as 'Gold-fringed moth of India.' Females possess wing expanse from 22 to 30 mm. while in males it is from 16 to 25 mm.

Head.—Front is conical and protruded beyond the eyes in males, rounded in females. This feature distinguishes it from *Chilo zonellus* because in the latter the front is conical and protruded in both males and females.

Wing-venation (*Plate XXXVI, fig. 2-a*). Fore-wing.—Vein Sc. arises free but fuses with R_1 in front of the cell. Distally the two diverge again into Sc. and R_1. The stalk of R_3 and R_4 is equal to the branch R_4 but bigger than R_3. The veins $R_3 + R_4$, R_5 and M_1, arise at equal distance from each other at the apex of the cell.

Hind wing (Plate XXXVI, fig. 2-b).—Sc. and R_1 arise free but immediately fuse to form a common vein Sc. *plus* R_1, which fuses with Rs near the angle of the cell. After running for a distance they diverge into Sc. *plus* R_1 and Rs. M_1 arises from Rs before it coalesces with Sc+R_1 but it originates beyond the upper angle of the cell. PTV is faint but the angle is that of 90°. M_2 and M_3 arise together in a short stalk from the lower angle of the cell,

Female genitalia : Internal.—Accessory glands a little less developed while other structures resemble those of *Argyria sticticraspis* Hmpsn.

External.—Ovipositer and collar as in *Argyria sticticraspis*. Genital opening surrounded by chitinous folds. Chitinous plate absent. Bursa copulatrix and ductus bursæ simple ; signum absent.

Male genitalia : Internal.—Testes dorso-ventrally flattened in the form of a disc. Vasa deferentia are closely approximated at origin, dilated afterwards to form vesicula seminalis. The two tubes fuse to form a single convoluted tube the ejaculatory duct to open at the adeagus. The accessory glands in the form of thin tubes communicating with vesicula seminalis.

External (*Plate XXXVII, figs. 3 and 4*).—Vinculum triangular, grooved and drawn out posteriorly. Anellus an incomplete ring, its lobes extending forward. Adeagus straight and pointed posteriorly. Penis arrow shaped. Cornutii present at the neck of the arrow. Harpes as in *Argyria sticticraspis* but hinged with vinculum. Tegumen short and triangular. Uncus with pointed apex, devoid of hook. Socii in the form of small sclerites, one on each side lying between gnathos and uncus.

PUPA

Disposal of different structures resembles *Argyria sticticraspis*. It differs from the latter in its cranial region which is neither rough nor raised up. A transverse ridge is present above the eye and is protruded like short horns. There is an incomplete circle of distinct spines on the seventh abdominal segment extending beyond the spiracles. The posterior extremity is divisible into dorsal and ventral halves, each possessingtwo pointed projections.

LARVA

The caterpillar very closely resembles that of *Argyria sticticraspis* in the general make-up of the body, the stripes, the tubercles and the spiracles (Fig. 3). It was for this reason that *Argyria sticticraspis* was so long confused with *Diatraea auricilia* ; the points of differentiation being the rim of the spiracle of *Diatraea auricilia* instead of being jet-black is grey in colour. The wall in front of the internal filaments is studded with minute papillae of different sizes gradually getting bigger towards the interior. There is no stage in larval existence when the tubercles become colourless. The fully mature larvae are comparatively bigger in size and measure from 25 to 30 mm. in length and about 4 mm. in breadth.

Larval details and chaetotaxy

Number of sclerites, setae and punctures are the same as in the larva of *Argyria sticticraspis*. The head setae A_1, A_2, and A_3 are almost in a right angle, resembling the arrangement met with in *Diatraea saccharalis*. Seta A_1 is more anteriorly removed from A_2 and puncture Aa is more approximated to A_2 than in *Argyria sticticraspis*. P_1 far behind Adf_1 while seta P_2 and puncture Pa far behind Adf_2. The distance between frontal seta F_1 and Adf_1 is less than the distance between Adf_1 and Adf_2. Pb not in a level with P_1 but posteriorly removed and approximated to L_1. The frontal punctures Fa considerably separated from each other

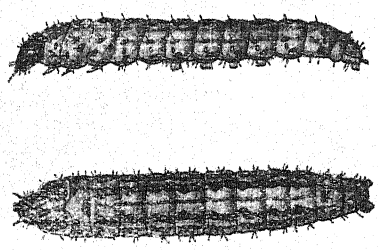


FIG. 3. Side and dorsal view of *Diatraea auricilia* Ddgn.

Labrum has median setae M_1, M_2 and M_3 arranged more or less in a right angle and therefore M_2 is not posterior to M_1 but at the same level. Puncture Ma lies behind M_1 and is approximated to M_1 than to M_2 as in the case of *Argyria sticticraspis*. Only two sensory papillae of epipharyngeal shield are present in the region below and in-between M_1 and M_2. Lateral seta La_3 lies at a higher level than M_3. The epipharyngeal cones Et lie between La_1 and M_2 instead of lying between La_2 and M_3 of *Argyria sticticraspis*.

Mouth-parts.—Mandibles with second tooth pointed and prominent. Cardo is reduced and extends over sub-mentum which extends a little beyond cardo and does not fuse with its fellow of the opposite side.

Thorax.—On prothoracic shield the puncture X has shifted behind Y. XY are far removed from seta Ia than in *Argyria sticticraspis*. Puncture Z midway between Ia and Ib instead of being near Ib. Va does not occur at any stage of larval life. Rest of the setae and tubercles are similar in distribution as in *Argyria sticticraspis*.

Abdomen.—Tubercles and setae resemble those of *Argyria sticticraspis* with the difference that trapezoid tubercles are big and make an angle of 90°. No central dorsal tubercles are developed. Xb makes its appearance on eighth abdominal segment and lies ventral to Xa. IIIa always keeps its individual identity and does not come in the sphere of III tubercle.

Pro-legs.—Crochets follow the same biordinal arrangement as in *Argyria sticticraspis*, but the circle is complete though the size gradually decreases towards the exterior.

EGG

Freshly laid eggs of *Diatraea auricilia* resemble the eggs of *Argyria sticticraspis* in size, shape, colour and in general arrangement.

LIFE-HISTORY

Copulation, oviposition and hatching resembles *Argyria sticticraspis*. Freshly hatched larvae measure about 1 mm. in length. The head is black and dorso-ventrally flattened. Prothoracic shield is of a dirty white colour like the rest of the body. The larvae possess only four stripes. The dorsal stripe being absent. Tubercles are grey and spines are black in colour. The larvae avoid light and take shelter on the under-surface of the leaves. The larvae are active and fragile and great devourers of green leaf tissues,

Second instar larvae.—First moult generally occurs on the third day after hatching but in some cases it occurs after five to nine days depending upon the food available. The dorsal stripe appears after the first moult. Body is semi-transparent and alimentary canal can be seen lying within. Crochets are in a semi-circle with a fewer number of spines than found in a mature caterpillar. The process of moulting resembles *Argyria sticticraspis* and each moult takes from thirty to forty-five minutes. There are five moults before the larva reaches maturity. The duration of various instars depends on the nature of food available.

The larval period varies considerably in different larvae hatched from the same egg mass. Some pupate after thirty days of larval life while others may take thirty-five to forty days and even more. It has been observed that larvae reared on shoots failed to pupate. They would always leave the shoot and pupate outside. It appears that mature larvae are incapable of making exit holes by boring through several layers of leaves. This explains why *Diatraea auricilia* does not occur in young plants and is only fond of grown-up canes. The internodes harbouring this borer fail to grow to a normal size.

Pupal period.—The pupal period lasts from eight to ten days. The progress of pupation is as follows :—

1st day.—Head region brown while body yellowish white, spiracles projected, stripes present.

2nd day.—Abdomen pale yellow, stripes persisting.

5th day.—General colour yellowish brown, eyes reddish brown and frontal horns dark brown.

8th day.—Pupa deep dark brown, no rolling movement of the posterior end.

10th day.—Emergence of the adult.

Summary of the life-cycle

Emergence of the imago completes the life-cycle. The incubation period takes five days, larva thirty-five to forty days and pupa eight to ten days, the whole cycle covering a total period of forty-five days in the laboratory during March and April.

SEASONAL HISTORY

Over-wintering larvae are stimulated to activity by the beginning of February and emergence of moths takes place by the middle of February and continues up to the end of March. The eggs of the first brood were freely laid in the laboratory cages but they were not found on the aftermath or ratoon. Moths of second brood came out in laboratory cages by the beginning of April, while some larvae emerged as late as the end of April. The second brood occurred during April and May. During this period not a single plant was found harbouring *Diatraea auricilia* larva either on the sprouts of the stubble or on the plant cane. With the breaking of monsoon and sowing of paddy, *Diatrae auricilia* larvae were found infesting paddy in June and July and sugarcane in September when the rains were over. Its infestation in grown-up canes was at its maximum in October and November. It appears that there are five generations in the year. How the first two generations are passed in the field could not be ascertained in spite of a thorough search in the majority.

of the graminacious crops growing in the vicinity of Pusa. It has not been recorded so far from the western districts of the United Provinces.

Diatraea venosata (Wlk)

ADULT

The wing expanse in females is 30 to 35 mm. and in males about 25 to 30 mm. Zehntner's [1898] account of *Diatraea striatalis* Snellen of Java closely applies to that of *Diatraea venosata* Wlk. in the length of labial palpi which are as long as the head and thorax, suffused with dark in males and ochraceous in females. Antennae are similar and so is the general colouration of the wings. Apex of fore-wing is drawn out to a fine point. In males the posterior border of fore-wing is sloping. The cell area is imperceptibly formed and the black spot of scales lies at the basal angle of the cell. Marginal spots are inconspicuous in males but prominent in females. The only difference being that there is a greater wing expanse in the females of *Diatraea striatalis* which varies from 36 to 38 mm. It may be due to climatic variations. These features leave very little doubt that the two are not identical.

Head.—Front rounded and protruded in males, flat in females. Antennae flat and lamellate in males. The segments are wider than long and serration is deep. The ocelli are absent altogether. Labrum straight with pilifers well-developed. Labial palpi long and pointed.

Wing venation: Fore-wing (Plate XXXVI, Fig. 3a and b).—The fusion of Sc and R_1 is more pronounced. The two diverge just near the margin into Sc and R_1. R_2 is approximated to the stalk of R_3 and R_4 and coalesced with the latter in females. Branch R_4 bigger than the stalk while R_5 smaller. M_2 and M_3 arise together but not stalked. R_4 to A_1 the veins are equidistant at the margin.

Hind-wing.—Sc + R_1 and Rs similarly disposed as in *Diatraea auricilia*. M_1 arises from Rs just when the latter is to fuse with Sc + R_1, beyond the cell. Angle PTV less than 90°. M_2 and M_3 are stalked for a distance. The stalk being smaller than either M_2 or M_3. Cu_1 curved near the angle of the cell. Cu_1a removed from the angle while Cu_1b arises a little beyond the cell.

Female genitalia: Internal.—The various structures are disposed on a plan very much resembling those of *Argyria sticticraspis*.

External.—Single stylet supports the collar of ninth segment. Genital opening without any chitinous plate but surrounded by chitinous folds which extend within to a circular girdle from where the ductus bursae is continued to bursa copulatrix. The ductus bursae is short but has several chitinised longitudinal folds below the girdle. Bursa copulatrix is dilated and signum is absent.

Male genitalia: Internal.—Similar to *Argyria sticticraspis*.

External (Plate XXXVII, figs. 5 and 6).—Vinculum slender, rounded and flat drawn out to a fine point posteriorly. Anellus plate extending as an arm from vinculum to support the adeagus tube. Juxta membraneous and closely applied to adeagus which is tubular and bears spines; penis large and prominent provided with several rows of spines. Harpes bluntly triangular and reduced. Tegumen, gnathos and uncus chaelate.

PUPA

The fronto-clypeal is flat with two spines. A sort of roughness which neither resembles ridges of *Argyria sticticraspis* nor the spines of *Diatraea auricilia* is present on fifth, sixth and seventh abdominal segments. It is bounded by a streak posteriorly which appears white in reflected light or when viewed from behind. These streaks persist as white lines after the emergence of moths. Two short and thick spines are present in the dorsal half of the anal segment, directed upward and backward.

LARVA

The caterpillars are comparatively larger in size than other borer larvae and measure from 25 to 30 mm. in length and are about 4·5 to 5 mm. in thickness. Stripes are four, violet in colour, dorsal stripe being absent (Fig 4.). The stripes of the two sides do not run with each other on the eighth abdominal segment. The tubercles are very big and are jet black in colour. Anterior trapezoid tubercles are round while the posterior ones are oval, the two lie at an angle of 35°. Ventral tubercles are grey instead of black. The tubercles lose their colour by the middle of October when hibernation commences. At this stage the caterpillar resembles the larva of *Chilo zonellus* in the colouration of the stripes. The two can be easily recognised from each other by the grey colour of the tubercles in the larvae of *Chilo zonellus*.

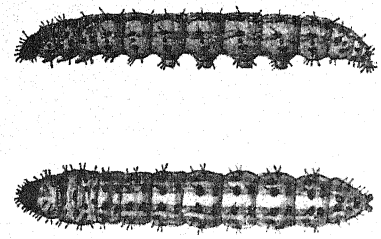


FIG. 4. Side and dorsal view of *Diatraea venosata* Wlk.

Spiracles and supra-spiracular tubercles lie on the lateral stripes, the former being latero-posterior of the latter instead of being directly below the tubercles, as in *Argyria sticticraspis* or *Diatrea auricilia* larvae. The spiracles are rounded than oval and lie on tracheal vessel which can be easily seen through the transparent chitin. The rim of the spiracle is jet black with grey space inside. The disposition of the filaments and papillae resembles *Diatraea auricilia*.

Larval details and chaetotaxy

Head.—Puncture Adfa lies ahead the junction of adfrontal suture with the longitudinal ridge. Adf_2 more posteriorly removed. The distance between F_1 and Adf_1 is less than the distance between Adf_1 and Adf_2. P_2 lies beyond the level of Adf_2 as in *Diatraea auricilia* but not on the same level as in *Argyria stricticraspis*. Puncture P_a is equidistant from P_2 and P_1 and all the three lie in a line. Pa almost in a level with Adf_2. Puncture Aa and setae A_1 and A_2 in a line and equidistant from each other. A_1, A_2

and A_3 lie in an angle greater than a right angle. The puncture La approximated to seta L_1 unlike that of *Argyria sticticraspis*. Ultra-posterior setae and puncture (x) big and prominent.

Mouth-parts.—Labrum closely resembles that of *Diatraea auricilia*, the differentiation being the shuffling of the setae of the median group towards the notch. The puncture Ma lies behind M_1 and M_2 and is equidistant from both. There is another puncture Mb posterior to Ma. The epipharyngeal papillae EP are approximated together and lie one on each side of the seta M_2.

Mandibles possess six prominent teeth which are projected and conical and clearly indicate that the larvae are great devourers of cane tissues.

Labium, maxillae and mentum built on the same plan as in *Argyria sticticraspis* or *Diatraea auricilia*. Cardo is heavily chitinised and has no glove-shaped projection. Its internal outline is convex and hangs over the sub-mental sclerites. The latter arise from the region of stripes and run up to the base of cardo.

Thorax.—The number of setae and punctures on prothoracic shield similar to *Argyria sticticraspis*. Puncture X and Y behind one another as in *Diatraea auricilia*. Puncture Z nearer to seta Ib. Shield is black at border and greyish brown pigment spots are absent. A prominent mid-dorsal fissure present. Seta IXa and IXb lie on a common tubercle and IXc fuses with its fellow of the opposite side to form a bisetose ventral tubercle in front of the leg. On meso and meta-thorax IXa, IXb and IXc are present as in *Diatraea auricilia* and *Argyria sticticraspis* and Va resembles the latter. Central dorsal tubercle is single on meso-thorax but it is divided into two on meta-thorax, one on each side of the mid-dorsal line.

Abdomen.—Trapezoid tubercles make an angle greater than 90°. Central dorsal tubercles are not present. Va is not repeated on any abdominal segments. IIIa always remains separate.

Life-history

Eggs are laid as described for *Argyria sticticraspis*. Incubation period takes from five to six days, larval existence continues from twenty-one to thirty days and pupation lasts from ten to twelve days during the active season. The larvae shrink in size at the approach of pupation and the tubercles lose their colour. The larva, spins a semi-transparent silken nest before pupation and lies quiscent in the nest during the pupal change. Over-wintering larvae take about fifteen days in pupal stage. The total period taken by one life-cycle varies from six to seven weeks.

Seasonal history

It attacks sugarcane in North Bihar during the monsoon months of July, August and September when cane is actually formed. It does not occur in young shoots. Its ravages are localised. It may occur abundantly in one field while it may be altogether absent half a mile away. The borer is at its maximum activity in September. Its intensity of attack goes down in October when hibernation begins. Some of *Diatraea venosata* larvae begin to hibernate from the middle of September and emerge in the following

spring. In laboratory cages larvae hibernated from the 20th of September 1930 and emerged as moths on the 9th of March 1931. During the period they are absent from sugarcane they abound freely in *Saccharum fuscum* (Ikri) and *Saccharum spontaneum* (Batri). This borer has recently been recorded from Dehra Dun and its life and seasonal histories are being worked out.

Chillo zonellus (Swinhoe)

ADULT -

Wing expanse of females varies from 25 to 30 mm. while those of males measure from 20 to 25 mm. only. The colouration of males differs from the account given by Hampson [1896] of *Chilo simplex* Butler. The costal area of fore-wing is not darkish but brown. The dark specks are more in number than what has been indicated by Hampson. It resembles *Crambus zonellus* Swinh. [1884], in its brown shadowy band running from apex of the fore-wing to the centre but differs in the colour of abdomen which is ochraceous instead of whitish. The last joint of labial palpi is never long but it is the shortest.

Head.—Front is bulging and is drawn out in the form of a conical projection. The cone is as much pronounced in males as in females. Antennae are flat and lamellate in males, filiform in females. Ocelli are present on black tubular projections just adjacent to antennae. Labial palpi three-jointed and double the length of the head. The last joint is short and conical. Maxillary palpi are ochraceous with last joint massive, flat and club-shaped. Labrum straight and pilifers present.

Wing-venation: Fore-wing (Plate XXXVI, fig. 4*a*).—Apex of the fore-wing rectangular in males but acute and produced in females. General description of veins resembles those of *Argyria sticticraspis* in both fore and hind wings. R_1 from the middle of the cell, approximated towards Sc which is free. R_2 is approximated to the stalk of $R_3 + R_4$ at its origin. The stalk is bigger than its branch R_3 but smaller in comparison to R_1. R_5 straight and from below the apex of the cell. PTV curved and the angle undifferentiated. All the veins are equidistant at the margin.

Hind-wing (Plate XXXVI, fig. 4*b*).—Sc + R_1 and Rs arise free but anastomosing in front of the cell. The fusion persists for about two-thirds the length of the wing when they diverge again into Sc + R_1 and Rs. M_1 arises from Rs within the area of the cell and, therefore. PTV originates from M_1 and makes an angle of 90°. M_2 and M_3 are stalked. Cu_1a from before but near the lower angle of the cell. The area of the cell is diminished and therefore, the apex of the cell is very much drawn in towards the base. Cross-vein PT in much reduced and TV is eight times the length of PT.

Female genitalia : Internal.—The various structures constituting the internal genitalia resemble those of *Argyria sticticraspis*.

External.—Ovipositor similar and so also the stylets attached to it. Genital opening lies in the notch on the chitinous plate on the eighth abdominal segment. Ductus bursae is lightly chitinised at its origin and bursa copula is much trix is without a signum.

Male genitalia : Internal.—Testes single, disc shaped. Vasa deferentia prominent and well separated. They in their course narrow down to swell up again into vesiculae seminalis. The two open into a triangular sinus by a

very narrow tube. The lateral extremities adjacent to the junction of vesiculae seminalis are extended below and are approximated together to form the accessory glands which lie below in convoluted loops. The apex of the sinus is drawn out into a tube—the ejaculatory duct—which opens on the adeagus.

External (Plate XXXVII, figs. 7 and 8).—Vinculum rounded and drawn out posteriorly, lateral walls thick and massive. Anellus triangular with huge lateral lobes arising from its dorsal margin. The distal extremity of the lobe resembles the fluke of an anchor, ventrally the anellus possesses a calcar with a long, stout spur projecting to a considerable distance below the adeagus and studded with hairs and spines. Juxta is closely applied to adeagus dorsally and is semi-cylindrical in shape. Adeagus is a long single tube with a rounded sack at the entry of the ejaculatory duct. Penis is sabre-shaped and extends beyond the uncus, with cornutii present at its apex. Harpes with a heavily chitinised basal lobe. Sacculus reduced and costa depressed. Transitilla absent as in others. Tegumen with lateral walls broad for a considerable distance. Uncus and gnathos form a chaela.

PUPA

In *Chilo zonellus* fronto-clypeal region is convex and bulges out towards the ventral side. Bases of wings have a semi-lunar comb-shaped prominence with a golden lustre. The pupa resembles much that of *Diatraea auricilia* in the nature of spines of fifth, sixth and seventh abdominal segments, the only point of differentiation being that in *Chilo zonellus* these spines do not extend beyond the spiracles on the seventh abdominal segments.

LARVA

General

The larva (FIG. 5) measures from 20 to 25 mm. and resembles the caterpillars of *Diatraea auricilia* and of *Argyria sticticraspis* in general disposition of the body and its tubercles. But the stripes are four, dorsal stripe absent, where it resembles *Diatraea venosata* but the jet black tubercles of the latter do not occur (Fig. 5). The larvae show a sexual dimorphism in the disposition of grey tubercles and stripes, which is not hitherto marked in other striped caterpillars. In one form, the trapezoid tubercles are big and prominent and all the four tubercles lie very close to each other. In such a case the two sub-dorsal stripes are less prominent and run on the borders of these tubercles and are well separated from each other as in fig. 5(*a*). The moths developing from such larvae are generally female. In the other form the trapezoid tubercles are of medium size, less prominent and are well separated from each other. The violet stripes are very prominent and run over the tubercles. These two sub-dorsals stripes run with each other anteriorly, posteriorly and in the middle of the trapezoid tubercles on each segment as in fig. 5(*b*). The developing moths from such larvae are mostly males. Sometimes it becomes difficult to decide whether the larvae will give rise to male or female moths. In such cases greater importance in sex determination should be placed on the size of tubercles than the stripes.

Spiracles.—The jet black rim and the internal filaments guarding the stigmatal opening resemble those of *Argyria sticticraspis* but the space within is dark here.

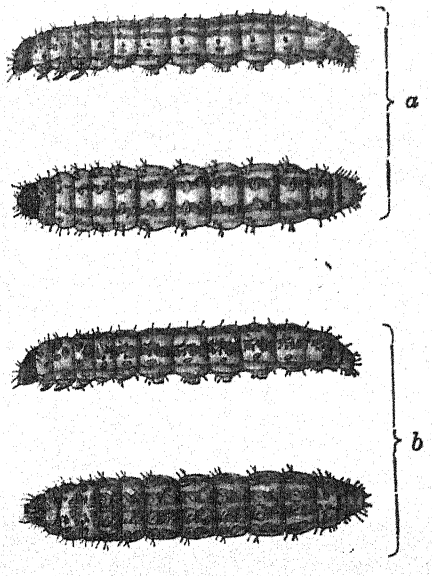


FIG. 5. Side and dorsal view of *Chilo zonellus* Swinh.

Larval details and chaetotaxy

Head.—It is light brown in colour with dark brown mouth-parts. Seta P_2 lies at a level with Adf_2 as in *Argyria sticticraspis* and unlike that of *Diatraea auricilia* and *Diatraea venosata* where it is considerably thrown back. Puncture Pa is approximated to P_2 and consequently the distance between Pa and P_1 is more than in any of the larvae described above. The distance between Adf_1 and Adf_2 is more than the distance between Adf_1 and adfrontal seta F_1. Punctures Fa well separated. Aa, A_1 and A_2 close together and in a straight line. The distance between A_3 and Aa less than the distance in any of the larvae described in the preceding pages. Ultra-posterior setae X surround the puncture posteriorly.

Labrum.—M_3 at a higher level than La_3, M_1, M_2 and M_3 possess a puncture each. The puncture Mb of M_1 lies in front of it towards the notch. Mc latero-posterior of M_3 and Ma latero-posterior of M_2 and behind M_1. Epipharyngeal sensory cones lie between the setae M_3 and La_3. Sensory papillae are absent. Cardo glove-shaped and projected. Sub-mentum sclerites extend beyond the base of cardo.

Thorax.—Pro-thoracic shield has usual number of setae. The puncture X is absent. Y near the seta Ia as observed on the prothoracic shield of *Argyria sticticraspis* and *Diatraea venosata.* Z is approached to Ib. IXa and IXb correspond with IXab of *Diatraea venosata* with the only difference that they lie on separate tubercles. On meso- and meta-thorax the tubercle Va is setaless and resembles Va of *Argyria sticticraspis* in colour and *Diatraea venosata* in size. IXa is present anterior to leg on meso- and with the addition of IXb on meta-thorax. Single puncture is present on the first joint of each thoracic leg which ends in a straight spine.

Abdomen.—Usual number of setae and tubercles are present with Va repeated prominently on first to seventh abdominal segments. It is characteristic of *Chilo zonellus* but does not occur on eighth, ninth and tenth abdominal segments. Trapezoid tubercles from second to eighth abdominal segments possess two to four deep brown pigment spots in front of the setae. These spots never occur on the anterior trapezoid tubercles of the first abdominal segment. Pre-spiracular tubercle IIIa is joined to III on the first abdominal segment in cases where the stripes are running together but it is free in others.

Pro-legs.—Crochets are arranged in a circle decreasing in size towards the exterior. The spines are arranged in triordinal series, smallest lying between the medium and biggest.

LIFE-HISTORY

Copulation and oviposition resemble *Argyria sticticraspis*. Hatching occurs in the early hours before sunrise. There have been cases when hatching has been noted about 10 A.M. and 4 P.M. The larvae after coming out from the egg measure from 2 to 2·5 mm. in length about 0·25 to 0·3 mm. in breadth. Head and prothorax is dark brown while the rest of the body is translucent, dirty white in colour. Tubercles are violet instead of grey or brown as has been noted in *Argyria sticticraspis* and *Diatraea auricilia*. Stripes are absent and pro-legs are peg-like with two to three crochets.

Larvae are fond of maize leaves and are attracted by light at this stage. It was observed in the laboratory that all the larvae collected on the side of the jar which was facing the window. When this lighted side of the jar was turned away from the window the larvae again collected on that side which was then facing the window. If the jar is inverted the larvae immediately take an about-turn and crawl upward. One of their peculiar habits is of collecting together. These habits explain the crowding of these larvae on the tassel of the maize plants which generally harbour as many as fifty larvae. The sexual dimorphism in the larvae is evident after the first moult.

Duration of the larval period.—In active season it lasts from sixteen to twenty-four days. They undergo the usual number of five instars covering a period from two to eleven days. It is seldom that one or two larvae prolong their larval life to as many as thirty days hatched from the same egg mass.

Pupa stage.—The various colour changes from yellow to brown are undergone in the same way as has been described in the case of *Argyria sticticraspis*. The pupal period taken by males and females differs in different months. In the case of males it varies from four to seven days, while in females the time taken is from six to nine days.

Duration of the life-cycle.—The total period from egg-laying to the emergence of adult varies from twenty-six to thirty-five days in the active season in July, vix. egg four to six days, larva sixteen to twenty-four days, pupa five to seven days.

SEASONAL HISTORY

Seasonal history resembles that of *Argyria sticticraspis*. Over-wintesing larvae begin to emerge as moths by the end of March and continue to do so till the beginning of May. The borer remains active till the middle of November. Depending upon the shortest period in life-cycle it can be presumed

that it has at least five broods. The period from the 19th of November 1929 to the 25th of March 1930, was noted to be a time of absolute rest. Fletcher and Ghosh [1921] have observed its longest resting period extending from September to about July and August. This phenomenon is rare. During the period under study not a single larva took such a long time in completing one generation.

Chilo zonellus occurs in sugarcane in case the cane fields are in the neighbourhood of those of paddy or maize. In July and August 1930 sugarcane was grown in the compound of pathological laboratory. On the other side of it rice and maize were growing in the pot-culture house of the mycological section. It was the only instance when *Chilo zonellus* larvae ocurred in sugarcane. They were infesting rice and maize abundantly.

Second instar larvae were released on young sugarcane plants on the 26th of July 1931. Many of these larvae failed to penetrate the internodes but bored the mid-rib of the leaf. The growth was very slow. The larvae entering the central leaf-sheath could chew only a part and indicated ' dead heart ' on the 14th of August, i.e. after a period of nineteen days. These young larvae did not live on the hard tissues of the cane leaves and ultimately died. Mature larvae of course thrive well on sugarcane whether young or old. Side by side the larvae were released on maize plants from $1\frac{1}{2}$ ft. to $2\frac{1}{2}$ ft. high on the same date as on sugarcane and of the same instar. The result was that dead heart was indicated on the 31st July in the youngest of the lot. While all these plants were brought to the ground on the 4th of August with the majority of leaves dead. The larval growth is more accelerated in maize than in sugarcane. It is probably the reason why *Chilo zonellus* larvae prefer young maize to old plants and this explains their infestation of the inflorescence when the maize plants are quite grown up. It is not a regular pest of sugarcane as had been indicated by Stebbing [1903]. He writes :—

> ' *Chilo simplex* so far does not appear to be a bad pest in the sugarcane at Seeraha ; it occurs far less frequently there than the other two borers. But if the insect thrives and multiplies greatly in maize which is grown throughout the district during rainy season it will certainly spread to the sugarcane if the two crops are grown near to one another.'

Conclusions

It would appear from the table of difference (Appendix) that the specific differences afforded by the structural details leave little doubt that the insects described above belong to four different species and can be easily recognised from each other by the nature of the front, the ocelli, the labial palpi, the wing venation, and the genitalia of adults, characteristic markings of the pupae and the nature of stripes and tubercles of the caterpillars.

The presence of ocelli, short labial palpi and the nature of the front bring *Argyria sticticraspis* much nearer to *Diatraea auricilia*, while the male internal genitalia of *Diatraea venosata* resemble those of *Argyria sticticraspis*. This opens a field for the study of generic position of *Argyria sticticraspis*. Any taxonomist of this group will find this thesis of great use in his further work. Besides, the information on anatomical details coupled with life-history

and seasonal incidence will help a good deal those who are trying to combat these pests and who meet them in their day-to-day work in the field of sugarcane entomology.

ACKNOWLEDGEMENTS

The author carried out this work as post-graduate student at the Imperial Institute of Agricultural Research, Pusa, under the guidance of T. Bainbrigge Fletcher, Esq., R.N., F.E.S., F.L.S., F.Z.S., lately Imperial Entomologist, to whom the author is very much indebted, and further expresses his gratitude to Mr. N. Sen, Artist, Entomological section for the majority of drawings. Thanks are due to Imperial Council of Agricultural Research for financing the United Provinces Sugarcane Research Scheme, wherein the author got an opportunity to revise this work at Sugarcane Research Station, Muzaffarnagar.

REFERENCES

Busck, A. and Heinrich, C. (1921). *Proc. Ent. Soc.* (*Washington*) **23**, 145
Butler (1880). *Proc. Zool. Soc.* (*London*), 690
Comstock, J. H. (1918). *Wings of Insect*
Cotes, E. C. (1889). *Ind. Mus. Notes* **1**, 22-7
——— (1893). *Ind. Mus. Notes* **2**, 145-76; **3**, 55-62
——— (1894). *Ind. Mus. Notes* **3**, 63-4
Dudgeon (1905). *Bom. Nat. His. Soc. J.* **16**, 405
Dyar, H. G. and Heinrich, C. (1927). *U. S. Nat. Mus. Pros.* **71**, 1-48
Fletcher, T. B. (1926-27). *Rep. Imp. Ent.*, 57-60.
Fletcher, T. B. and Ghosh, C. C. (1921). *Agric. Res. Inst.* (*Pusa*) *Bull.* **102**. *3rd Ent. Meet.* (1919) 355-417. *Proc. 2nd Ent. Meet.* (1917) 141-46, 174, 182
Forbes, William, T. M. (1910). *Ann. Ent. Soc. Amer.* **3**, 94-132
Fracker, S. B. (1815). *Biol. Mono.* **2**, 169
Ghosh, C. C. (1922). *Agric. Res. Inst. Pusa Bull.* **134** (*or Proc. 4th Ent. Meet.*, pp. 106-36)
Hampson, G. F. (1895). *Proc. Zool. Soc.* (*London*) 897-974 and 953-54
——— (1896). *Bom. Nat. Hist. Soc. J.* **21**, 1250
——— (1898). *Fauna of India* **4**, 46, 63
——— (1918). *Proc. Zool. Soc.* 128
——— (1919). *Ann. Mag. Nat. Hist.* **3**, 449
Holloway, T. E. and Loftin, T. U. (1919). *U. S. Dept. Agric. Bull.* **746**
Lefroy, H. Maxwell (1900). *West. Ind. Bull.* **1**, 4
——— (1906). *Agric. J. Ind.* **1**, 97-113
——— (1908). *Agric. J. Ind.* **3**, 104
——— (1910). *Agric. Res. Inst.* (*Pusa*) *Bull.* **19**
Mukerji, B. J. (1857). *Agric. & Hort. Soc. Ind.* **5**, 355-8
Snellen, P. C. T. (1890-91). *Tijdschrift voor Entomologis*, 349-53
Stebbing, E. C. (1903). *Ind. Mus. Notes* **5**, 66, 10
Swinhoe (1884). *Proc. Zool. Soc.* (*London*), 528
——— (1885). *Proc. Zool. Soc.* (*London*) 879
Walker, (1863). *Catalogue* **27**, 144
Zehtner, H. (1898). *Levenswigze en hestrigding der boorders. Medeo. proefestat. East Java* **23**, 21

ABBREVIATIONS

Chaetotaxy—	FR	Front.
	ADFR	Adfrontal ridge.
	LR	Longitudinal ridge
	Adfs	Adfrontal sutures
	E_1 and E_2	Setae of epistoma
	Fa	Frontal puncture
	Adf_1	Adfrontal seta
	F_1	Frontal seta
	A_1, A_2, A_3	Anterior setae
	Adfa	Adfrontal puncture
	P_1, P_2	Posterior setae
	Pb	Posterior puncture
	L_1	Lateral seta
	La	Lateral puncture
	O_1, O_2, O_3	Oceller setae
	Oa	Ocellar puncture
	So_1, So_2, So_3	Sub-ocellar setae
	G_1	Genal seta
	Ga	Genal puncture
	M_1, M_2, M_3	Median setae
	La_1, La_2, La_3	Lateral setae
	Ma	Median puncture
	Et.	Epipharyngeal setae
	Ep.	Epiphyrangeal papillae
	CDT.	Central dorsal tubercle

Appendix

TABLE OF DIFFERENCES

Stage	Structures	*Argyria sticticraspis* Hmpsn.	*Diatraea auricilia* Ddgn.	*Diatraea venosata* Wlk.	*Chilo zonellus* Swinh.
I. Adult	*Head and mouth-parts* (i) Front	Convex in ♂ rounded in ♀.	Conical in ♂ rounded in ♀.	Rounded in ♂ flat in ♀.	Conical and projected in ♂ and ♀.
	(ii) Ocelli	Present . . .	Present . . .	Absent . . .	Present but projected.
	(iii) Antennae .	Ringed black and white	Alternating grey and ochraceous.	Flat and lamellate with deep serration. Mixed with dark in ♂. Ochraceous in ♀.	Ochraceous in both ♂ and ♀.
	(iv) Labial palpi	As long as the head .	As long as the head .	As long as the head and thorax, last joint long and pointed.	Double the length of the head with last joint shortest.
	Wing venation (i) Fore-wing	Sc separate and unbranched. M_2 and M_3 arise separately.	Sc arises free but fuses with R_1. M_2 and M_3 arise separately.	Sc arises free but fuses with R_1+M_2 and M_3 arise together but not stalked.	Sc separate and unbranched. M_2 and M_3 arise closely but do not fuse with each other.
	(ii) Hind-wing .	M_1 arises from Rs before the angle of the cell. M_2 and M_3 arise in a common short stalk.	M_1 arises from Rs after the angle of the cell, M_2 and M_3 arise in a common stalk.	M_1 arises from Rs just at the place of its fusion with Sc and R_1. M_2 and M_3 arise in a long stalk.	M_1 arises from Rs within the area of the cell. M_2 and M_3 arise together in a short stalk.

TABLE OF DIFFERENCES—*contd.*

Stage	Structures	*Argyria sticticraspis* Hmpsn.	*Diatraea auricilia* Ddgn.	*Diatraea venosata* Wlk.	*Chilo zonellus* Swinh.
I. Adult—*contd.*	*Female genitalia* (i) Genital opening.	Funnel shaped with a tri-angular plate.	Genital opening circular with chitinous folds.	Genital opening with slightly chitinised folds but having heavily chitinised girdle below.	Genital opening with a chitinous plate having extended horn.
	(ii) Ductus bursae	Slender with chitinous folds.	Slender without any chitinous folds.	Ductus bursae with chitinous plates.	No chitinous folds.
	(iii) Signum .	Signum present .	No signum . .	No signum . .	No signum.
	Male genitalia (*a*) Internal (i) Vasa deferentia.	In pear-shaped pouches	In closely applied tubes	Like *Argyria sticticraspis.*	The thick tubes opening into a triangular sinus.
	(ii) Accessory gland.	A pair of thread-like single tubes.	Two thin and separate tubes.	Like *Argyria sticticraspis.*	Fully developed tubes convoluted and closely applied to each other.
	(*b*) External (i) Annellus .	Semi-cylindrical .	Incomplete ring with extended horns.	Plate-like . . .	With a flat base and very much extended lobes like an anchor.
	(ii) Juxta .	Bilobed . . .	Bilobed . . .	Membraneous and closely applied.	Semi-cylindrical, closely applied.

	(iii) Penis .	Curved and sword shaped.	Arrow-like . .	With spines . .	Sabre-shaped
	(iv) Socii .	Absent . . .	Present . . .	Absent . . .	Absent.
II. Pupa	(i) 5th, 6th, 7th abdominal segments.	Ridges present on the dorsal side of 5th, 6th and 7th abdominal segments. They extend up to the spiracles on 5th and 6th but the ring is complete on 7th abdominal segment.	Incomplete ring and spines extending up to the spiracles on 5th and 6th and extending beyond the spiracles on 7th abdominal segment.	Roughness on 5th, 6th, 7th abdominal segments with whitish streaks appearing as prominent white lines after emergence.	Incomplete ring of spines on 5th, 6th and 7th abdominal segments, none of them extending beyond the spiracles.
	(ii) Anal end .	4 spines at the anal end directed towards the posterior.	No spines . . .	Anal end with two short and thick spines.	Only projections without spines at the anal end.
III. Caterpillar.	(i) Number of Violet stripes.	5	5	4	4
	(ii) Tubercles .	Grey ; become colourless after July and in all hibernating caterpillars.	Remain of grey colour throughout.	Dorsal jet black, ventral grey, become colourless in all hibernating larvae.	Grey ; trapezoid tubercles in 2 sizes ; tubercles do not change colour, well-separated medium sized tubercles with dorsal stripes running with each other develop into ♂. Big tubercles with well-separated stripes develop into ♀.

TABLE OF DIFFERENCES—*concld.*

Stage	Structures	*Argyria sticticraspis* Hmpsn.	*Diatraea auricilia* Ddgn.	*Diatraea venosata* Wlk.	*Chilo zonellus* Swinh.
III. Caterpillar—*contd.*	(iii) Spiracles .	Oval, jet black rim with clear space inside; opening guarded by filaments.	Oval, grey coloured rim with clear space inside opening guarded by papillae.	Round, jet black with grey space, opening guarded by papillae.	Oval, jet black rim with dark space opening guarded by papillae and fibrillae.
	(iv) Head setae and punctures.	Anterior setae A_1, A_2, A_3 do not form a right angle. The distance between frontal seta F_1 and adfrontal seta Adf_1 is more than Adf_1 and Adf_2.	Ant. setae A_1, A_2, A_3 forming a right angle. The distance between F_1 and Adf_1 is less than the distance between Adf_1 and Adf_2.	A_1, A_2 and A_3 form an angle greater than a right angle.	A_1, A_2 and A_3 as in *Diatraea venosata*.
		Posterior seta P parallel with Adf_1 and Pa with Adfa.	P_1 far behind Adf_1 and P_2 behind Adf_2.	As in *Diatraea auricilia*	P_1 behind adf_1 but P_2 at a level with Adf_2.
	(v) Mouth-parts (1) Labrum	Lateral seta La_3 at a level with M_3.	La_3 at a higher level than M_3.	La_3 at a lower level than M_3 which is more approximated towards the notch.	As in *Diatraea venosata*.
		Sensory papillae of the epipharyngeal plate round about M_2.	Sensory papillae between M_1 and M_2.	Sensory papillae one on each side of M_2.	Sensory papillae are absent.
	(2) Sub-mentum	Sub-mentum in two pieces runs up to the limits of cardo and the sclerites fuse with each other.	Pieces extend beyond cardo and do not fuse with each other.	Pieces arise from the region of stripes and do not fuse with each other.	Pieces extend beyond the limits of cardo.

(vi) Thorax—Setae and tubercles.	Va with a short spine present on meso- and meta-thoracic segments.	Va does not occur at any stage.	Va present but devoid of seta.	Va present but setaless.
(vii) Abdomen—Setae and tubercles.	Central dorsal tubercles present.	Central dorsal tubercle absent.	No central dorsal tubercle.	No central dorsal tubercle.
	Va setaless on I to IV abdominal segments.	Va absent.	Va absent . . .	Va present from 1st to 7th abdominal segments.
	III unisetose with IIIa in proximity. IIIa is separate from III on 2nd to 7th abdominal segments, but joins the III on 8th abdominal segment.	IIIa is always separate	IIIa always separate .	IIIa joins the III on 1st abdominal segment in cases where stripes are running together, otherwise separate.
	Trapezoid angle 50° .	Trapezoid angle 90° .	Trapezoid angle 35° .	Trapezoid angle 30°
(viii) Crochets .	Crochets are in the form of an incomplete circle open towards the exterior. Spines of crochets are biordinal in arrangement.	Crochets are arranged in a complete circle with spines following biordinal arrangement.	Crochets are arranged in a circle though the size of spines decreases towards the exterior. The arrangement of spines is biordinal.	Crochets in complete circle, size decreasing towards the exterior. The arrangement is triordinal.

CHILO TRYPETES BISSET (PYRALIDAE)—A NEW PEST OF SUGARCANE FROM THE PUNJAB

BY

KHAN A. RAHMAN, B.Sc. (EDIN.), PH.D. (CANTAB.), F.R.E.S.

AND

D. N. TANDON, L.AG., B.SC. (AGRI.)

Punjab Agricultural College, Lyallpur

(Received for publication on 29 November 1939)

(With Plate XXXVIII)

INTRODUCTION

IN India sugarcane is damaged by several caterpillars of pyralid moths. M. Afzal Husain, Entomologist to Government, Punjab, Lyallpur studied the distribution of these borers in the Punjab in 1923 by examining sugarcane samples from all over the sugarcane-growing tracts of the province. A variety of *barani* (rain-fed) sugarcane grown locally at Sialkot yielded a species of caterpillars which was different from the common species of sugarcane borers. M. Afzal Husain gave this caterpillar the name of ' new pyralid borer '. Moths were bred out and submitted to the Imperial Research Institute, Pusa and British Museum, London, for identification. In spite of repeated submissions of fresh material annually, the pest remained unnamed till October 1938, when the senior author wrote to Sir Guy Marshall for its specific identification. This resulted in Mr G. A. Bisset naming it as *Chilo trypetes* sp. nov. (Pyralidae : Lepidoptera).

DISTRIBUTION

Chilo trypetes Bisset has a restricted distribution in the Punjab and has so far been recorded from the tehsils of Pathankot, Batala, and Gurdaspur (Gurdaspur district), and Mukerian (Hoshiarpur district).

FOOD-PLANTS

The pest is monophagous and feeds only on sugarcane. It has neither been found in other gramineous plants (cultivated or wild) in the fields, nor has it ever fed on such plants as guinae grass (*Pannicum maximum*), maize (*Zea Mays*), *sarkanda* (*Saccharum sara*) and a few wild grasses offered to it in the laboratory.

CHILO TRYPETES BISSET

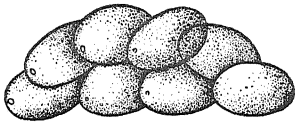


FIG. 1. Egg cluster

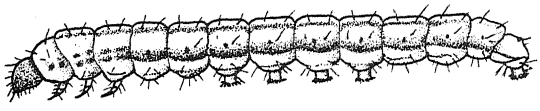


FIG. 2. Full-grown caterpillar ($\times 2\frac{1}{4}$)



FIG. 3. Pupa ($\times 2\frac{1}{4}$)

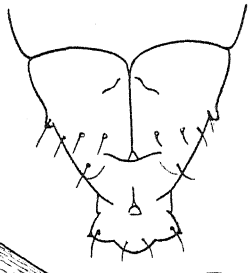


FIG. 3 *a*. Tip of abdomen of pupa (highly magnified)

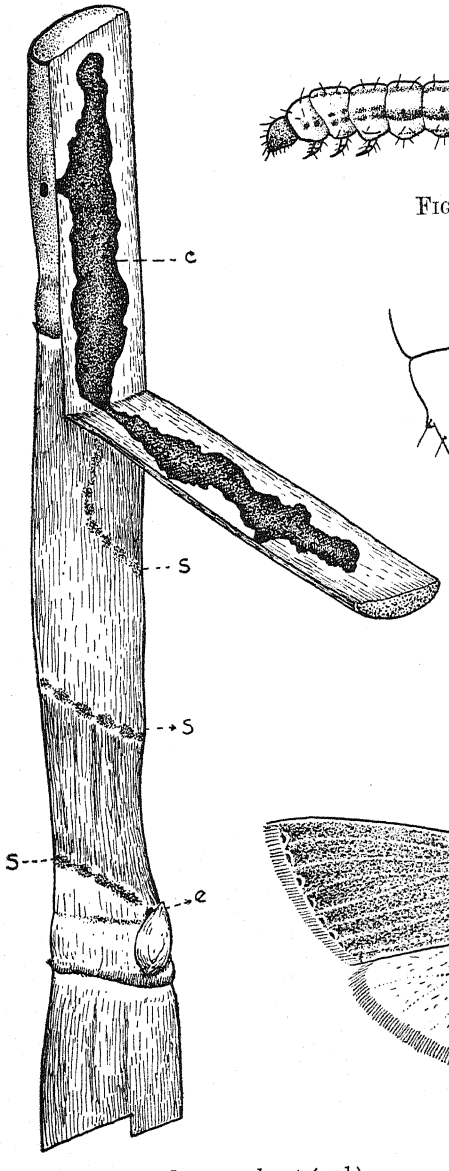


FIG. 5. Damaged cane shoot ($\times \frac{1}{2}$)

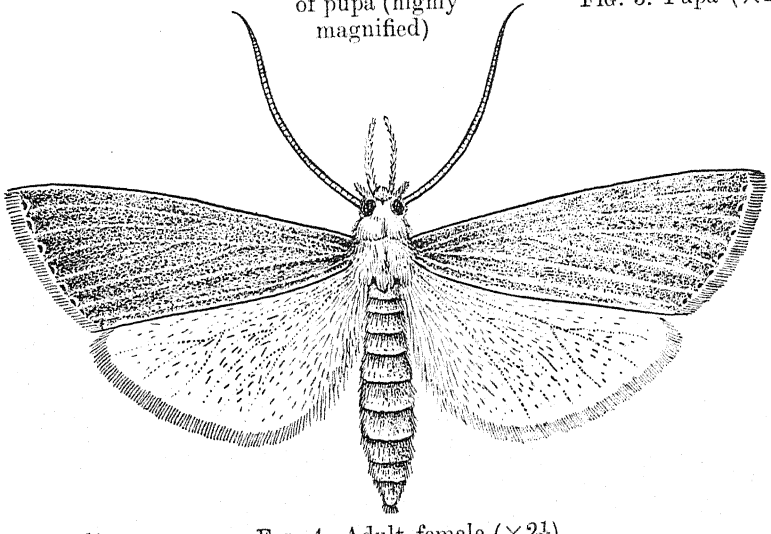


FIG. 4. Adult female ($\times 2\frac{1}{4}$)

Description of various stages

Egg (Plate XXXVIII, fig. 1)*

Length 0·65-0·86 mm., breadth 0·42-0·53. Flattened and scale-like. Glistening white to pale cream when freshly laid, changing to dark grey before hatching.

Caterpillar (Plate XXXVIII, fig. 2)

A full-grown caterpillar measures 25-28 mm. in length and 2·5-3·0 mm. in breadth. Body cylindrical, sparingly clothed in short setae which arise from tubercles. Head light orange, rest of the body creamy white ornamented with four longitudinal reddish-brown stripes situated as follows : One on each side along the spiracles and the other on either side of the dorsal vessel; the spiracular (or lateral) stripes being very prominent, particularly between the 1st and 9th abdominal segments. Crochets on prolegs are arranged in uniordinal uniserial circle.

Pupa (Plate XXXVIII, figs. 3 and 3a)

Length 14-19 mm., breadth 2·3-3·0 mm. Body more or less smooth, creamy white when freshly formed, but later on changes to yellowish-brown. Thorax with a dorsal median longitudinal ridge. Abdominal spiracles oval slightly raised and deep brown in colour. Spiracular reddish-brown stripes faintly indicated. Last abdominal segment terminating in a prominent broad ridge, distal margin of which is armed with three small spines as indicated in Plate XXXVIII, fig. 3*a*.

Adult (Plate XXXVIII, fig. 4)

G. A. Bisset [1939] describes the moth as follows :

Male.—25-27 mm. Dorsal and lateral surfaces of the palpi, thorax, abdomen and the upper surface of the fore-wing with seven darkish spots between the veins. Under-surfaces lighter to white. Hind wings white. Labial palpi projecting forwards more than twice the length of the head ; second segment twice as long as third. Head with a conical prominence ending in a short point ; undersides of prominence flattened, the edge of the flat surface being slightly produced in front to a point directly beneath the other. Antennae serrate and finely ciliated.

Female.—29-32 mm. Similar to male but fewer dusky brown scales on the fore-wing and the antennae simple.

Life-history

The moth forces its way out of its pupal cell through the protected exit hole made for the purpose by the caterpillar before pupation. The adults become active at night when they mate, copulation lasting ten to twenty-three minutes.

* Sketches presented in Plate XXXVIII were made by M. D. Siddiqi, Artist, Entomological Section, Lyallpur, under the supervision of the senior author.

A female lays her eggs in clusters at night on the leaf-sheath near the upper nodal rings of the stem. They are arranged in rows and overlap each other like the scales on a bird's leg (Plate XXXVIII, fig. 1). Each egg-cluster contains three to sixty-five eggs.

The number of eggs laid by a female varies greatly (Table I).

TABLE I

Oviposition record of Chilo trypetes *Bisset at Gurdaspur*

Number	Pairs sleeved		Total number of eggs laid
	From	To	
1	31 July	4 Aug.	105
2	4 Aug.	8 Aug.	182
3	6 Aug.	10 Aug.	230
4	7 Aug.	12 Aug.	113
5	8 Aug.	12 Aug.	198

Thus a female is capable of laying 230 eggs in her life-time.

The eggs usually hatch in the morning. The egg-stage occupies nine to eleven days (Table II).

TABLE II

Duration (in days) of egg-stage of Chilo trypetes *Bisset at Gurdaspur*

Number	Eggs laid	Eggs hatched	Duration of egg-stage
			Days
1	4 Aug.	14 Aug.	10
2	5 Aug.	15 Aug.	10
3	9 Aug.	19 Aug.	10
4	13 Aug.	22 Aug.	9
5	16 Aug.	26 Aug.	10
6	19 Aug.	30 Aug.	11
7	20 Aug.	30 Aug.	10

The larval stage lasts for forty-eight to sixty-four days (Table III).

TABLE III

Duration (in days) of larval stage of Chilo trypetes *Bisset at Gurdaspur*

Number	Eggs hatched	Larvae pupated	Duration of larval stage
			Days
1	3 July	5 Sept.	64
2	14 July	31 Aug.	48
3	12 Aug.	5 Oct.	54
4	14 Aug.	5 Oct.	52

Prior to entering into pupation a full-grown caterpillar constructs a pupal cell in the burrow in which it was feeding. The cell is internally lined with silken threads. It also provides the cell with an exit hole by cutting out a small circular piece from the rind of sugarcane stem and covering the hole thus made by a silken web. Afterwards it transforms itself into a pupa Table IV gives the duration of the pupal stage.

TABLE IV

Duration (in days) of pupal stage of Chilo trypetes *Bisset at Gurdaspur*

Number	Larvae pupated	Adults emerged	Duration of pupal stage
			Days
1	2 Aug.	10 Aug.	8
2	4 Aug.	17 Aug.	13
3	9 Aug.	15 Aug.	6
4	3 Aug.	12 Aug.	9

SEASONAL HISTORY

The adults appear on the wing during June-July, deposit eggs and start the infestation. From July to October all stages of *Chilo trypetes* Bisset are met with in the fields, the pest completing one generation during this period. The moths of the second generation start emergence about September when they lay eggs and the caterpillars hatching out of these eggs descend to the basal portion of the cane in November where they remain till the following June.

Nature and extent of damage

Chilo trypetes Bisset starts taking toll of the crop when the plants are fairly grown up and the internodes are well formed.

The mode of entry of the caterpillars into the stem of sugarcane is quite peculiar. On hatching from the eggs they feed for a while on the buds situated on the top first or second internode and then they bore into it (internode) from near the buds (Plate XXXVIII, fig. 5*e*). They feed on the tissue first below the rind boring their way upwards (from the point of entry) in a spiral manner (Plate XXXVIII, fig. 5*s*) : externally this passage appears as a dark spiral streak, which on closer examination is found to be made up of a series of punctures (made by the caterpillars) lying side by side like the beads in a rosary. When about two-thirds of the internode is damaged in this manner, the caterpillars bore deeper into the softer tissue of the cane and feed by making a single, straight and central tunnel (Plate XXXVIII, fig. 5*c*).

Up to the second moult the caterpillars feed gregariously when there may be twenty-seven to forty-two of them in a single bore. Afterwards they disperse and lead a solitary life.

Injury by this borer is quite characteristic. In the beginning of the attack (i.e. when the caterpillars are feeding just below the rind (Plate XXXVIII, fig. 5*s*) the side leaves wither, but as the attack proceeds further (i.e. when the caterpillars have made a central bore (Plate XXXVIII, fig. 5*c*), the entire whorl of the leaves (including the central leaves) dries up and the crop presents a blasted appearance.* The attacked canes fail to grow. The dark spiral streak (Plate XXXVIII, fig. 5*s*) renders the affected internode weak, which breaks off easily when shaken by wind or a passing animal.

The damage by *Chilo trypetes* Bisset ranges from 15 to 20 per cent of the total crop during normal years, but in years of serious damage it may be as high as 50 per cent. The damage by this pest is at its maximum during August-September. *Barani* (rain-fed) crop suffers the most and, of the various Coimbatore varieties of sugarcane, Co 205 and Co 285 are the worst sufferers.

Control

Chilo trypetes Bisset is not a difficult pest to control. As mentioned above it spends the period from November to June as a resting caterpillar in sugarcane stubbles. Therefore simple, cheap and most effective method to deal with it is to plough up the sugarcane stubbles any time from November to May with a furrow turning plough. The uprooted stubbles should be collected and destroyed whenever convenient before June. A clean-up campaign in the localities where it is a serious pest will prove very helpful in subjugating it. If possible ratooning of sugarcane in infested areas should be given up.

When the attack is in progress all the damaged top shoots, recognisable by the symptoms described above, should be collected and destroyed. This is best done during July when the young caterpillars are feeding gregariously inside the top shoots.

* In case of attack by other borers it is only the central shoot that dries up and is called a ' dead-heart ', the rest of the leaves remaining quite healthy and green.

To check its inroads into uninfested localities seed cane free from *Chilo trypetes* Bisset should only be imported.

ACKNOWLEDGEMENT

This work was undertaken at the suggestion of Khan Bahadur M. Afzal Husain, Entomologist to Government, Punjab, Lyallpur (appointed Vice-Chancellor of the University of the Punjab in October 1938) to whom we are grateful both for suggesting the problem and for help and advice during the progress of this investigation.

SUMMARY

Chilo trypetes Bisset (Pyralidae : Lepidoptera) is a new pest of sugarcane which was discovered for the first time in the Punjab in 1923 by M. Afzal Husain, Entomologist to Government, Punjab, Lyallpur. It has a restricted distribution and has so far been recorded from Sialkot, Gurdaspur, Batala, Pathankot and Mukerian (Hoshiarpur). It feeds only on sugarcane and shows special preference for *barani* (rain-fed) crop.

Different stages of the pest are described and figured.

The pest is active from June-July to October when it completes its life-cycle in sixty-three to eighty-eight days. The moths of the second generation appear about September when they lay eggs and these give rise to caterpillars, which remain in sugarcane stubbles from November to June.

It begins to take toll of the crop when the plants are fairly grown up and the internodes are well-formed. Damage by this pest ranges from 15 to 20 per cent during normal years, but in years of serious attack it may be as high as 50 per cent. The leaves of the attacked cane dry up and the plant fails to grow; it breaks off easily when shaken by wind or a passing animal.

The pest can be controlled effectively by ploughing up the sugarcane stubbles any time from November to June. The uprooted stubbles should be collected and destroyed. In July the damaged canes should be removed and destroyed to kill the larvae.

REFERENCE

Bisset, G. A. (1933). *Proc. Roy. Ent. Soc.* (*London*) (B) **8**, 3

Rahman, Khan A. (1940). *Pb. Agric. Coll. Mag.* (*Lyallpur*) **7**; 19

STUIDIES ON EDIBLES FROM *BORASSUS FLABELLIFER* (PALMYRA-PALM) WITH SPECIAL REFERENCE TO *NIRA* OR SWEET TODDY

BY

K. MITRA, M.B., D.P.H. (CAL.), D.T.M. & H. (ENG.), F.S.S. (LOND.)

Officer-in-charge

AND

H. C. MITTRA, M.Sc. (PAT.)

Chemist

Nutrition Scheme, Public Health Laboratories, Bankipur

(Received for publication on 6 March 1940)

INTRODUCTION

PALMYRA palm or *tarh*, as it is commonly known in Upper India, grows abundantly in the province of Bihar. But unfortunately this spontaneous and bountiful gift of nature has not so far been utilised to the fullest benefit of the population therein. About twenty years ago, Ghosh [1920] drew attention to this neglected source of sugar in Bihar and lamented over the fact that 'richly saccharine juices yielded by this tree are converted into toddy' providing a cheap intoxicating drink, freely indulged in by the lower class people. On a most liberal estimate not more than 25 to 30 per cent of the trees are tapped in Bihar for this purpose.

The professional toddy tappers in this province belong to a community known as Pasis. The last census (1931) enumerated a population of 172,061 Pasis in the provinces of Bihar and Orissa of which 20,576 or 11·95 per cent were recorded to be earning their livelihood as toddy tappers and the rest were obviously their dependents.

The present investigations were started with a view to finding out how the various types of produce from palmyra-palm could be profitably utilised to the betterment of the state of nutrition of the people. This could be effected by encouraging the consumption of those edibles comparatively rich in protective elements and by better utilisation of all the possible food products from the tree. The present time seems to be a most opportune moment for dissemination of knowledge on the subject outlined above as with the introduction of prohibition in Bihar (and other parts of India as well) increasingly large number of men who had been eking out their miserable existence by tapping and vending the fermented juice (*toddy*), are finding themselves unemployed. According to Blatter [1926], who has made an extensive study on the subject of the palms of British India and Ceylon, 'every part of the palmyra-palm is turned in account in some way or other. By far the most important aspect of this tree is a source o food'.

Different edibles

Nira.—This is the Hindusthani name given to the sweet unfermented juice obtained from the inflorescence of both the male and femal trees.* There is a common belief prevalent that the sap from male trees is sweeter than that from the female. Sethi and Ghosh [1932], fter analy is of s crose content of the juice of male and female palm at Patna and Sabour, state that though individual female trees have at times been found to yield a richer juice, usually the juice from female trees is weaker in sucrose content than that of the male. The authors of this paper could not confirm their findings as this investigation was started late in the season when the juice in male trees had dried up. *Nira* is a refreshing drink with pleasant sweet taste. On keeping without preservative in hot humid climate even for a short time it gradually turns turbid and slightly sour in taste. This is how the fermentation begins.

Tarh-ka-koa.—This is the name given to the almost clear jelly-like albuminous fluid found within the shell of the young fruit. The fluid gradually hardens and assumes a white colour with increasing opacity, and develops a fibrous coat all round. During the hot months the soft gelatinous kernel (before hardening sets in) is supposed to be an exceedingly refreshing article of food. The pulp of the green fruit is sliced (minus the seed) and given to the cattle as a galactagogue in certain parts of this province.

Ripe fruit.—The mesocarp or pulp of the ripe fruit is golden coloured, luscious, sweetish and pasty in texture. Poorer people at times consume it raw or else mixed with a little amount of sugar and flour and fried n oil to make t into sweet cakes. In Ceylon the pulp is spread over mat in a thick layer, dried in the sun and preserved for consumption during winter months. This dried and preserved pulp is known there as *punatoo.*

Guthli-ka-gudda.—This is the Hindusthani name given to the cream-coloured substance of cheesy consistency which develops inside the stone of the ripe fruit as soon as small roots can be seen springing out from the fibrous surface of the seeds. It has a sweet, pleasant, taste and liked by children.

Seedlings.—When the seedlings are still very tender (about two to three months old) their beautiful parchment-like outer coating is removed and the pulp of stem is either boiled and dried in the sun or simply dried in the sun and then both of them ground into fine flour. The flour is made into various kinds of meals or gruel in South India and Ceylon.

Chemical composition of edibles

The estimation of protein, fat, carbohydrate, etc. were carried out according to the methods prescribed by the Association of the Official Agricultural Chemists [1930]. The assay of sugars was done by the well-known reducing test by Fehling's solution. The results are shown in Table I.

It is evident from Table I that with the exception of *nira* the other edibles are rich in mineral matter. They are of course not very rich sources of calcium or phosphorus. The increased concentration of calcium in treated *nira* and

* Similar sap from coconut (*Cocos nucifera*), date (*Phœnix dactylifera*) and sago (*Metroxylon sago*) palms are also known as '*nira*'.

TABLE I

Chemical composition of some of the edibles from palmyra-palm per 100 gm. of each foodstuff

Name of foodstuff	Where from obtained	Moisture per cent	Protein	Ether or fat extractives	Mineral matter	Crude fibres	Carbohydrates	Calcium	Phosphorus	Total sugar	Reducing sugar	Disaccharides	Total caloric value
			Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.			
Nira (June)	Patna	85·94	0·23	0·02	0·29	...	13·52	0·006	0·007	12·6	0·4	11·6	56·6
Nira (July)	Patna	85·89	0·31	0·02	0·31	...	13·47	0·007	0·008	12·2	0·3	11·2	56·7
Nira treated with* lime and decanted.	Patna	85·76	0·30	0·02	0·38	...	13·54	0·030	0·001	Samd as above No change in sugars			56·9
Nira treated with† lime well shaken.	Patna	86·13	0·28	0·02	0·38	...	13·19	...	...				
Tarh gur	A. I. V. I. A. Bengal	9·61	1·37	0·11	1·54	...	87·37	0·124	0·055	82·2	3·1	75·2	364·9
Tarh gur	Jaffna, Ceylon	8·32	1·04	0·19	3·15	...	87·30	0·861	0·051	82·6	1·7	76·0	364·0
Tarh gur	Experimental *gur*-making centre, Patna	8·61	1·03	0·08	1·81	...	88·47	0·225	0·044	84·0	2·0	79·9	367·7
Gudhli-ka-gudda	Patna	80·99	0·75	0·12	0·85	...	17·29	0·024	0·116	...	...	...	75·1
Pulp ripe fruit	Patna	77·22	0·67	0·15	0·68	...	21·28	0·009	0·033	...	...	...	91·4
Preserved pulp	Jaffna, Ceylon	22·70	1·60	0·14	3·37	...	72·19	0·087	0·070	...	...	...	303·8
Tarh-ka-koa	Patna	92·60	0·64	0·10	0·26	0·11	6·29	0·005	0·016	...	...	...	27·0
Flour (boiled)	Jaffna, Ceylon	12·88	4·59	0·32	1·40	1·75	79·06	0·013	0·119	...	...	...	347·2
Flour (sun-dried)	Jaffna, Ceylon	12·06	4·81	0·31	1·91	1·49	80·91	0·010	0·155	...	...	...	354·2

* 0·4 gm. of slaked lime (Ca 51·45 per cent) per 200 c.c. after 10 hours. † 0·25 gm. of slaked lime (Ca 51·45 per cent) per 200 c.c. after 10 hours.

gur (jaggery) is due to the extraneous lime added as preservative. Further it appears that limed *nira* after decantation shows considerable loss of phosphorus. Probably the phosphorus of the *nira* combines with calcium in the lime and settles down as a precipitate.

The flour prepared from the seedling contains about 5 per cent protein and can compare very favourably with flour prepared from any other vegetable (particularly tubers). The food value of the preserved pulp more than justifies its introduction as an edible in areas where palmyra-palm is grown in abundance.

Carotene and ascorbic acid

The carotene and ascorbic acid content of *nira*, fresh pulp from the ripe fruit, preserved pulp, *tarh-ka-koa* and *guthli-ka-gudda* were assayed according to the methods detailed by the authors [Mitra, Mittra and Ray, 1940]. The results are given in Table II.

Table II

Estimation of carotene and ascorbic acid

Name of the edible	Carotene in mg. per 100 gm.	l-ascorbic acid in mg. per 100 gm.
Fresh pulp of the fruit	7·58	24·0
Guthli-ka-gudda	0·04	11·3
Nira	*Nil*	5·7*
Preserved pulp	12·48	12·1
Tarh-ka-koa	*Nil*	13·1

* Measured per 100 c.c.

In the case of *nira* the maximum ascorbic acid content per 100 c.c. was found to be 14·6 mg. and 8·1 mg. in a series of twenty-one estimations on different days with different samples. But the commoner findings were often in the neighbourhood of 6·0 mg. Sokhey [1939] working with coconut palm has found on average an ascorbic acid content of 8·0 mg. per 100 c.c. of fresh juice in Bombay. The fresh pulp seems to be very rich in carotene and ascorbic acid, and preserved pulp seems to be still richer in both the protective elements.

Fermentation and inversion of sugars in *nira*

Of all the types of edibles available from the palmyra-palm *nira* is by far the most abundant and at the same time extremely unstable. Sethi and Ghosh [1932], after recording the yield from twenty trees for a period of three weeks, found that the average daily yield from a tree came up to 12·68 lb.es 1·78 S. E.* Thus the daily collection of a Pasi tapping about fifteen trees

* The mean and standard error were calculated by the senior author from the table of yield supplied in the text referred to.

comes to at least 150 lb. on a very conservative estimate. This large quantity of precious juice could hardly be allowed to go to waste or converted into cheap toddy. The only alternative seems to be the preservation of the juice before its ultimate disposal.

Fermentation of the juice takes place by the action of yeasts, moulds and bacteria which split up the disaccharides (usually sucrose) at first into monosaccharides by process of inversion ('invert sugar') and finally into alcohol. The degree of fermentation undergone by any liquid for purposes of comparative study can be measured either by assessing the number of yeast cells, moulds and bacteria in a known volume on a graduated haemocytometer slide under the microscope or by estimation of alcohol. The former method was found to be tedious and trying besides being inaccurate and was consequently abandoned. The alcohol was estimated by the usual methods of distillation and corrections for temperature, etc. made according to the table compiled by Jenkins [1927].

With the beginning of fermentation this almost transparent sweet and pleasant beverage turns into an opaque and frothy juice with a slightly acid and pungent taste, commonly known as toddy. If the temperature conditions be suitable the amount of fermentation is a function of time. It was found on the average that the juice or sap with a sucrose-content of 12·4 gm. per 100 c.c. yielded 8·51 per cent proof or 4·88 per cent by volume of alcohol after thirty hours' fermentation and 11·61 per cent proof or 6·40 per cent by volume of alcohol after complete fermentation has taken place in five days' time under ordinary room temperature at Patna in the hot and humid month of July. It has been previously observed by Annett *et al.* [1916-21] in the case of date-palm juice that though fermentation or formation of alcohol may be arrested by some chemicals yet the inversion of the valuable sucrose in the juice may persist through the action of the enzyme invertase rendering the juice (or the *gur* prepared therefrom) less sweet and consequently depreciating its ultimate commercial value and attractiveness. This has been found to be true in the case of palmyra-palm juice also. *Nira* as it trickles down from the tree has an acid reaction and the *p*H was found to vary between 5·0 and 4·5. Nightly collection of *nira* in smoked pots early in the morning before sunrise gave an acid reaction and the *p*H was found in the neighbourhood of 4·5 to 4·0. Fermentation and hydrolysis of sugars in the juice completely stopped when the *p*H was 8·0 or over.

Collection of *nira*

For the purposes of this investigation the sap was daily collected in earthenware pots, '*labni*', commonly used by the tappers. The pots were fixed on to the tree for the collection of the juice every evening immediately before dusk and brought down to the laboratory for analysis at about quarter to five in the next morning. The samples were analysed and preservative added immediately on arrival. The effect of the preservative on the juice was studied after ten hours, i.e. at 3 P.M. on the assumption that within ten hours of collection the juice would be disposed of either for immediate consumption as a drink or ultimately deposited in the boiling pan for manufacture of *gur* or jaggery.

Every afternoon before sending out the pots for collection they were emptied out of their contents, washed with water, both inside and outside. The pots were then half filled with water, heated to boiling point and kept on boiling for at least fifteen minutes. The pots were subsequently emptied, heated on open Bunsen flame to kill all residual and yeast cells. Finally the pots were smoked over burning straw and leaves. It was found out by experiment (estimation of alcohol) that pots treated in such a way behaved as good as new pots as far as fermentation was concerned.

The amount of invert sugar in the juice collected in smoked pots and without any other preservatives at night was found generally in the neighbourhood of 0·5 gm. and at times exceeded 0·6 gm. per 100 c.c. in the morning. Sometimes this sugar was found to be in the neighbourhood of 0·4 gm. per 100 c.c. of the juice or even below this level.

On the assumption that the estimation of sugars in the morning collection of *nira* even in smoked pots is not likely to furnish a correct picture of the sucrose content of the juice as it trickles from the tree and basing on the authors' experience (discussed later) that lime completely stops, hydrolysis collections were made from the same tree in excessively limed and unlimed (control) pots during the night. It was found that the juice in the limed pots contained as little as 0·05 to 0·06 gm. of invert sugar per 100 c.c. which did not comprise even 0·5 per cent of the total sugar content of the juice. The juice in the control pots showed as usual ten times the amount. The spathes were thoroughly washed with clean water before the pots were tied for the night.

Preservative of choice

An attempt was made to find out a non-poisonous chemical which would not only arrest fermentation but also effectively stop inversion of sugar. Table III summarises the results of investigation with six different types of the more common preservatives tried by the authors. In each case pure E. Merck chemicals were used except in the case of slaked lime. Ordinary bazar lime with a calcium content of 51·45 per cent in finely powdered state and devoid of grits was used throughout the investigation. The formalin used being 40 per cent of solution of formaldehyde.

In each case the minimum dose of the preservative effective in arresting fermentation for ten hours had to be individually worked out by different sets of preliminary experiments. Though tapped from the same tree the samples of *nira* used were collected on different dates. The invert sugar-content of the *nira* in the experiments detailed above varied from 0·5 to 0·6 gm. per 100 c.c. and in two cases it exceeded 0·7 gm. per 100 c.c. When the invert sugar-content of the juice in the morning was found to be in the neighbourhood of 0·4 gm. per 100 c.c. proportionately a much smaller dose in each case was needed to effectively stop fermentation for ten hours. Further with a juice having an invert sugar-content of 0·5 to 0·6 gm. per 100 c.c. the fermentation could be arrested for twenty-four hours, if need be, by doses bigger than that shown in column 2 of Table III. Table IV gives the dosage of the different chemicals necessary to arrest the fermentation in both the cases.

TABLE III

Effect of chemicals on fermentation and hydrolysis of sugars in 200 c.c. of nira *in 10 hours*

Preservative used	Dose per 200 c.c. of juice	Alcohol per cent by volume (morning collection)	Alcohol per cent by volume (after 10 hours)	Total sugars, gm. per 100 c.c. (morning)	Total sugars, gm. per 100 c.c. (after 10 hours)	Invert sugar, gm. per 100 c.c. (morning)	Invert sugar, gm. per 100 c.c. (after 10 hours)	Loss of disaccharides in gm. per 100 c.c. in 10 hours	Ascorbic acid, mg. per 100 c.c. (morning)	Loss of ascorbic acid, mg. per 100 c.c. in 10 hours
Slaked lime (Ca 51·45 per cent)	0·25 gm.	0·07	0·07	11·29	11·24	0·725	0·720	*Nil*	6·31	3·21
Boric acid	0·40 ,,	0·03	0·03	12·28	12·20	0·420	0·640	0·19	4·89	0·52
Formalin	4 drops	0·06	0·07	12·56	12·48	0·605	1·110	0·55	6·01	1·18
Benzoic acid	0·10 gm.	0·07	0·06	12·40	12·34	0·583	1·180	0·62	6·31	1·05
Lime *plus* sodium hydrosulphite'	(0 20+0·13) gm.	0·10	0·10	12·40	12·34	0·583	1·770	1·18	4·07	?
Na-hydrosulphite	0·40 gm.	0·10	0·10	11·29	11·29	0·725	2·240	1·45	4·07	?
Salicylic acid	0·10 ,,	0·06	0·06	12·40	11·31	0·583	2·400	1·83	6·31	2·06

TABLE IV

Dosage of chemicals necessary to arrest fermentation in 200 c.c. of nira

Different preservatives	Minimum dose required to arrest fermentation in *nira*	
	Containing 0·4 gm. (app.) invert sugar per 100 c.c.	Containing 0·6 gm. (app.) of invert sugar per 100 c.c.
Slaked lime	0·20 gm.	0·25 gm.
Boric acid	0·30 „	0·60 „
Formalin	3 drops	6 drops
Benzoic acid	0·07 gm.	0·15 gm.
Na-hydrosulphite	0·03 „	0·05 „
Salicylic acid	0·08 „	0·17 „

It appears from the study of Table III that slaked lime, of all preservatives, tends to stop the fermentation of *nira* and also the inversion of sucrose. The effective dose 0·25 gm. per 200 c.c. comes to about 87·6 grains per gallon. Even if this quantity be exceeded it can exert no poisonous effect on the system.

When the requisite amount of slaked lime is added to *nira* and the solution is well shaken a precipitate is formed which settles down in twenty to thirty minutes leaving the supernatant liquid clear. This precipitate consists of colloidal matter and a large proportion of the phosphate and very little of nitrogen as would appear from Table I. With all the other preservatives tried the juice remained turbid all through.

Benzoic and salicylic acids according to the authors' experience were the most difficult antiseptics to tackle. Before they could exert any antiseptic action complete pulverisation was essential. Further, being insoluble in water, they could not effectively stop fermentation when placed inside the collecting pots in the evening. They could only exert their preservative properties when thoroughly shaken with the juice in wide-mouthed-glass-stoppered bottles inside the laboratory. Formalin and sodium hydrosulphite were very effective in stopping fermentation in small doses but could not prevent hydrolysis of sugars.

Lime is best put inside the pot as a thin coating and it was found essential that the same should remain moist till the trickling of the juice inside begins, otherwise part of it was converted into inert calcium carbonate. It was also invariably found that some amount of lime at the top remained undissolved

by the juice. Another difficulty was that the total volume of secretion of the nightly juice could not be definitely anticipated in the evening when the pots were tied on with the preservatives.

Provided the number of collecting pots in one tree remained constant and the temperature conditions did not undergo material alteration it was not found difficult to roughly estimate the amount of juice anticipated and consequently the dosage of lime. In the authors' series the average collection with four pots and subsequently two pots from one tree spread over a period of $2\frac{1}{2}$ months came up to 306 c.c., 415 c.c. and 517·2 c.c. respectively. The details are shown in Table V.

Approximately in a pot (*labni*) of 2-litre capacity 1·0 gm. of slaked lime was found to prevent hydrolysis and fermentation completely in a collection of about 500 c.c. during the night. Slight overdosing of the pots with lime has to be done for reasons stated above. In case the collection turns out to be too small resulting in overdosing of the juice it should be remembered that calcium compound with sucrose can be decomposed with carbon dioxide without the sweetness being impaired. But once inversion starts sucrose is irreparably lost.

The ascorbic acid is one of the most important constituents of the fresh juice from the aspect of nutrition in children. The effects of the various preservatives on this vitamin has been worked out and the results incorporated in Table III. The figures estimated after treatment with sodium hydrosulphite were misleading as this particular preservative was found to exert reducing action on the dye 2 : 6 dichlorophenolindophenol, no reliance could thus be placed on the results of titration. Another interesting observation was that ordinary slaked lime in the concentration recommended as a preservative does not completely destroy vitamin C in the *nira*.

TABLE V

Average nightly collection of the juice in c.c.

Period of collection	Number of pots tied	Average per pot in c. c.	
		Mean	S. E.
Middle of June to middle of July	4	306·0	11·96
Middle of July to 1st week of August	4	415·5	9·62
2nd to 4th week of August	2	517·2	17·07

An attempt was made to estimate the amount of levulose ordinarily present in *nira*. Of all the tests mentioned by Clarke [1934] the resorcinol test and ammonium molybdate test seemed to be of practical importance. But in the former case heating with concentrated hydrochloric acid always resulted in hydrolysis of the sucrose-content and thus the amount of free

levulose present could not be estimated. The latter test though said to be a specific for levulose could not be used for estimation in this case as it was found to yield unsatisfactory results in cases where levulose content was low.

Discussion on the findings

Except the preparation of the flour from the seedling and the preserved pulp all the edibles from the tree are consumed in some parts of this province. Now that the nutritive value of the edibles are known, people all over (wherever this tree grows wild) and the professional vendors particularly should be advised as how to utilise the produce to their best advantage both from economic as also health point of view. People may also be advised to store the ripe fruit as preserved pulp.

The main point in the problem is the ultimate disposal of *nira*. Indiscriminate propaganda on the use of *nira* as a fruit drink is likely to yield doubtful results. As in localities where one pound of *nira* costs as much as one pound of milk (this condition does exist in certain parts of Bihar) the latter should be given preference. Then again the people have to be educated into *nira*-drinking habit and arrangements made for the transport of the juice to bigger towns and cities for consumption. In rural areas very few people are rich enough to pay for such (fruit) drinks.

Recently Sokhey [1939] has suggested the preparation of levulose from *nira*, advantage being taken of the fact that in *nira*, fermentation may be stopped, but hydrolysis may be allowed to proceed by invertase so that sucrose be converted into equal parts of glucose and levulose. Levulose is a very costly sugar and may well repay the efforts but its manufacture is not possible unless a well-equipped factory arranges for the transport and regular supply of the juice and its conversion into levulose.

The other possible alternative seems to be to convert it into *gur* or jaggery according to the practice followed in Ceylon and at present in certain parts of Madras and Bengal. The details of the methods of *gur* making and its advantages are available from the reports of Gokhale [1920], Sethi and Ghosh [1932] and many others. If seriously worked out as a cottage industry *gur*-making would help in raising the economic standard of the Pasis and thereby consolidating the efforts for the success of prohibition.

Summary

All the different edibles from palmyra-palm were analysed chemically with a view to finding out their nutritive value. The most abundant produce from the tree was found to be the *nira* or the sweet sap exuding from the crushed inflorescence of both the male and female trees.

Nira, unless quickly treated with preservatives, ferments easily in ordinary temperature to form *toddy*, a cheap alcoholic drink popular with the lower classes. Of all the preservatives tried, slaked lime was found to be the most easily available, cheap and efficient in arresting fermentation as also hydrolysis of sugars. The minimum effective dosages of the other preservatives, e.g. boric acid, formalin, benzoic acid, sodium hydrosulphite and salicylic acid have also been worked out. Except slaked lime none of the others could prevent hydrolysis of sugars. The pots should be washed and smoked daily.

Nira as it trickles down from the tree contains about 6·0 mg. ascorbic acid per 100 c.c. The sugar-content is about 12 per cent. It contains no carotene.

The pulp of the ripe fruit as also the preserved pulp (*punatoo* in Sinhalese) are rich sources of vitamins A and C. The flour made out of the seedling (two or three months old) compares favourably with other common flours made out of root vegetables (tubers). *Gur* prepared from limed *nira* obtained from Jaffna (Ceylon), Bengal and Bihar have also been analysed and found to be rich in mineral matter, specially calcium.

ACKNOWLEDGEMENTS

The authors are grateful to Mr E. W. Aryanayakam, Secretary, Basic Education Scheme, Wardha and to Dr P. C. Ghosh, Secretary, Bengal Branch of the All-India Village Industries Association, for the supply of various samples of *gur* and other edibles. To Lt.-Col. S. L. Mitra, I.M.S., Director of Public Health, Bihar, the authors are indebted for his valuable suggestion and encouragement.

REFERENCES

Annett, H. E. ; Pal, G. B. and Chatterji, I. B. (1916-21). *Mem. Dept. Agric. Ind.* (*Chem. Ser.*) **5**, No. 3.

Association of Official Agricultural Chemists (1930). '*Official and tentative methods of analysis*' : Washington (3rd Ed.)

Blatter, E. (1926). '*The palms of British India and Ceylon*' : Oxford University Press

Clarke, H. T. (1937). '*Handbook of organic analysis*' : Edward Arnold & Co., London (4th Ed.)

Ghosh, M. N. (1920). *Agric. J. Ind.* **15**, 32-9

Gokhale, V. G. (1920). *Bombay Dept. Agric. Bull.* **93**

Jenkins, R. L. (1927). '*Instructions for ascertaining real alcoholic strength, etc.*' : Bengal Govt. Press, Calcutta

Mitra K. ; Mittra, H. C. and Ray, A. C. (1940). *J. Ind. Chem. Soc.* **17**, 247-53.

Sethi, D. R. and Ghosh, M. N. (1932). '*The manufacture of gur and sugar from the juice of palmyra-palm in Bihar*' : Superintendent, Govt. Printing, Bihar and Orissa, Patna

Sokhey, S. S. (1939). Personal Communication. Copy of Report from Bombay Haffkine Institute to the Govt. of Bombay

A RAPID METHOD OF MEASUREMENT OF LEAF AREAS OF PLANTS

BY

N. C. THIRUMALACHARY, B.Sc. (Ag.)

Cotton Breeding Station, Coimbatore

(Received for publication on 11 September 1939)

(With three text-figures)

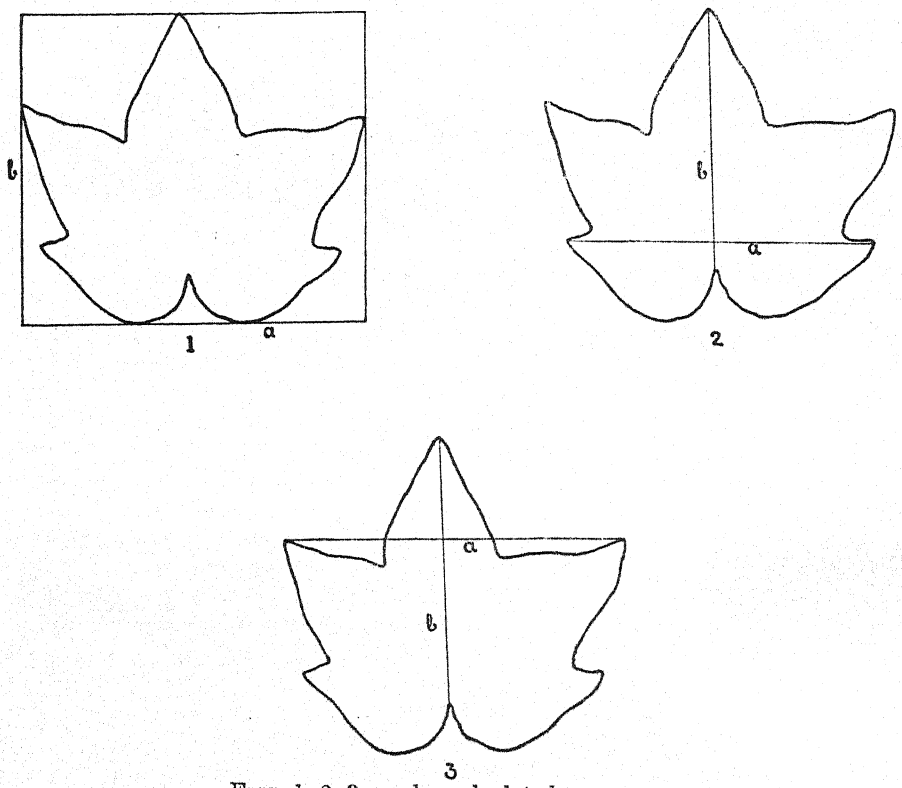
DETERMINATION of leaf areas of plants is one of the subjects that received the earliest and somewhat insistent attention at the hands of plant physiologists, as a result of which considerable degree of refinement and accuracy has become possible ; but many of the methods have been rendered difficult of application for developmental studies in field plants. The methods of Kidd, West and Briggs [1920] and of Watson [1937] necessitate the removal of leaves from the plant body and are not quite suitable for growth observations. Those of Frears [1935], Withrow [1935], Mitchell [1936] and Kraemer [1937] require the use of costly photo-electric apparatus and are ill-suited to field-scale operations. Gregory [1921], on the other hand, studied the correlations of a number of linear and angular measurements of the leaves of *Cucumus sativus* and formulated certain empirical relationships between them and the actual area. He found it necessary to use different formulæ for leaves of different ages which greatly reduced their direct application to field plants. A quick and reliable method satisfying this last requirement is still to be sought ; and this note embodies the results of efforts made in that direction in the course of studies on the water requirements of Cambodia cotton.

Methods and material

The material for the various measurements was derived from a field of Cambodia cotton (*G. hirsutum* L.) plants grown during 1934-35. The crop, at the time of sampling, was about four months old. The followng criteria were tested by actual measurements with a view to finding out how far each constitutes a reliable measure of leaf areas of cotton.

1. The area of the rectangle enclosing the entire leaf (Fig. 1).
2. The area of the rectangle the sides of which are formed by the length of the mid-rib and the maximum breadth between the basal lobes (Fig. 2).
3. The area of the rectangle whose sides can be represented by the length of the mid-rib and the breadth between the tips of the second and fourth lobes (Fig. 3).
4. By actually matching each leaf, the area of which is to be measured, against artificially prepared standards of known area cut out of ordinary cardboards.

The first three are self explanatory and do not require to be described. The last one is detailed briefly as under.



FIGS. 1, 2, 3. a × b = calculated area

About 100 leaves of ages ranging from ten to sixty days were collected from the field of Cambodia plants and their individual outlines sketched carefully on a piece of cardboard. The area of each of the 100 sketches was then carefully measured twice by means of a planimeter, and the average of the two readings was noted on each sketch. Thirty of these sketches were carefully chosen so as to constitute an ascending scale of areas. It was found that the smallest sketch was 3 sq. cm. in area and the largest was about 200 sq. cm., the difference between any two successive sketches in the scale being about 6 to 7 sq. cm. The selected sketches were cut out carefully and used as standards for matching.

The leaf, the area of which is to be measured, is then matched against its probable compeer among the standards, and the area of the closest match is taken to be the area of the leaf. It may be pointed out at this stage that a satisfactorily close match, deviating from the leaf by not more than 2 to 3 sq. cm. was almost always obtained, and greater divergences were of very rare occurrence. With a little experience the excess or deficit over the standard was easily estimated by mere eye judgment. All the final figures for the areas recorded in this note represent only such estimates.

Results

In Table I are given the results of measurements of forty-five leaves by methods 1, 2 and 3, while in Table II are given the areas of 100 leaves as measured by the cardboard method (4). In each case the corresponding areas as measured by the planimeter are also given for comparison.

Before discussing the results it may be pointed out that the first three methods do not give actual areas themselves but give only relative values of each area measured. The last method, on the other hand, gives what can be regarded as random estimates of the areas measured.

All the measurements have been statistically analysed and the correlation and regression coefficients obtained between the planimeter values and those worked out by methods 1, 2 and 3 are given in Table III. It will be seen that in all cases the correlation is high and significant. The percentage error of the regression varies from 4·9 to 3·7 for methods 1 and 2 which is not greater than that obtained by Gregory [1921]. In method 3, however, the error is considerably higher. It would, therefore, appear that for Cambodia leaves and leaves of similar shape, the complicated angular measurements used by Gregory can be dispensed with.

Further values by regression equation (Table I) were calculated for methods 1-3 and the standard deviations of the deviations of the estimates from the actual planimeter readings were worked out. For method 4 calculations were made separately for leaves below 50 sq. cm., between 50 and 100 sq. cm. and above 100 sq. cm. in area with a view to examine more closely the percentage error involved as the area of the leaf increases. The results are tabulated in Table IV.

Table I

Actual and calculated areas of cotton leaves (30 to 60 days old) in sq. cm.

Actual area as measured by planimeter	Area calculated by different methods			Area derived from regression equation		
	Method 1	Method 2	Method 3	Method 1	Method 2	Method 3
40·8	56·9	54·8	38·5	42·9	43·7	54·9
42·9	63·2	62·4	52·1	46·3	49·0	61·3
45·2	65·5	64·8	60·7	47·5	50·6	65·4
55·6	100·0	84·5	82·7	57·8	64·2	75·7
59·5	90·6	89·9	68·7	60·8	67·9	69·1
70·7	112·0	87·7	95·5	72·2	66·4	81·7
73·9	112·2	101·0	90·0	72·2	75·6	79·1
75·3	130·0	106·1	109·1	78·7	79·1	88·1
84·9	127·5	98·9	106·6	80·3	74·1	86·9
88·1	139·9	122·9	110·3	86·9	90·7	88·7
88·9	130·0	119·8	115·5	85·7	88·5	91·1
91·3	150·1	129·3	106·0	92·3	95·1	86·6
93·3	154·8	123·8	119·8	94·8	91·3	93·1

TABLE I—*contd.*

Actual area as measured by planimeter	Area calculated by different methods			Area derived from regression equation		
	Method 1	Method 2	Method 3	Method 1	Method 2	Method 3
94·0	158·7	126·7	100·9	96·9	93·3	84·3
97·5	157·4	126·4	136·3	96·2	93·1	100·9
97·6	154·9	129·9	131·0	94·9	95·5	98·4
97·7	161·6	109·4	139·2	98·4	93·4	102·2
99·6	169·7	129·2	143·9	102·8	95·0	104·5
100·3	165·1	142·7	139·2	100·3	104·3	102·3
101·7	170·6	127·0	137·0	103·2	97·5	101·2
102·5	182·3	144·0	159·3	109·4	105·2	111·7
103·2	163·8	135·3	141·9	99·6	99·2	103·5
104·8	182·1	147·4	161·5	103·1	107·6	112·7
112·8	184·9	139·6	158·9	110·8	106·2	111·5
115·5	190·3	159·7	150·0	113·6	116·1	107·3
117·2	192·7	154·4	155·6	114·9	112·4	110·0
117·8	180·9	169·7	158·7	113·6	123·0	111·4
117·9	186·0	163·2	146·5	111·3	118·5	105·7
118·1	217·1	182·1	190·0	120·8	121·5	126·1
118·3	208·8	193·4	161·2	124·4	129·3	112·6
120·0	200·2	175·5	182·1	118·9	127·0	122·4
120·4	206·7	167·9	176·0	122·3	121·7	119·5
120·8	205·8	179·1	174·2	121·3	129·5	118·7
121·3	178·2	154·1	146·1	117·2	112·2	105·5
121·8	226·2	160·3	184·9	122·6	116·5	123·7
126·3	204·3	174·0	182·4	121·0	125·9	126·6
131·4	232·1	182·4	187·2	135·7	131·7	124·8
133·5	224·0	177·6	188·4	131·5	128·4	125·4
135·9	232·4	182·7	203·3	135·9	131·9	132·4
136·6	220·3	164·7	192·6	129·5	119·5	127·4
137·7	256·7	204·5	205·7	135·8	147·0	133·5
145·2	232·5	191·0	170·2	136·0	137·7	116·8
162·6	297·2	211·7	247·0	170·3	151·9	152·8
162·8	266·1	233·6	214·7	156·8	167·1	157·7
177·4	289·6	256·7	322·1	169·2	173·0	189·2
Average 106·2	176·3	145·4	147·6			

TABLE II

Actual and calculated areas of cotton leaves (10 to 60 days old) in sq. c m. (method 4—cardboard method)

Actual area by planimeter	Calculated area	Actual area by planimeter	Calculated area
14·6	14·5	17·6	19·4
15·7	16·0	19·2	20·5

TABLE II—*contd.*

Actual area by planimeter	Calculated area	Actual area by planimeter	Calculated area
23·3	23·0	82·1	83·0
32·1	31·7	82·7	82·0
33·8	34·8	86·7	88·0
34·9	35·3	86·9	88·0
35·4	35·0	87·6	87·6
41·0	41·9	87·8	87·0
44·3	45·2	87·8	89·2
45·1	47·7	88·9	88·7
48·0	47·5	92·7	93·3
48·1	49·5	93·7	94·8
44·6	45·7	93·1	92·6
45·6	45·7	99·3	101·0
44·4	45·4	100·8	100·0
49·8	48·0	101·7	101·5
45·7	47·2	107·1	110·3
53·9	54·0	108·6	107·0
53·2	54·5	110·8	113·3
54·4	54·0	114·2	117·3
54·8	55·0	115·5	117·3
55·3	53·5	117·9	117·8
56·3	55·5	118·1	120·3
59·3	61·0	115·2	113·3
59·7	61·0	115·3	117·3
59·9	61·0	113·1	114·3
60·2	60·5	120·0	123·3
62·5	62·8	120·7	122·3
62·7	63·2	121·4	120·3
63·5	63·2	122·2	122·3
64·0	65·3	120·8	123·3
66·1	67·8	129·1	127·5
66·2	65·3	124·6	127·3
66·9	68·5	131·3	133·0
66·6	66·5	131·4	129·5
68·4	69·5	132·0	136·5
70·2	71·2	134·6	133·5
70·7	72·8	136·5	135·3
71·3	70·3	137·5	139·3
71·4	73·2	137·7	135·0
72·2	73·8	133·3	136·3
73·5	75·5	138·6	142·0
73·2	74·5	144·5	146·5
75·2	74·0	147·1	149·5
76·3	75·8	143·8	144·5
77·3	77·2	148·3	148·5
78·6	79·5	154·6	156·0
79·3	81·2	160·7	162·5
79·6	80·0	169·6	168·5
81·1	79·3	120·7	124·3
Average		86·85	87·44

TABLE III

Statistical analysis

Head	Methods			
	1	2	3	4
Correlation between planimeter value and those got from different methods	0·95±0·01	0·97±0·006	0·78±0·04	0·95±0·003
Regression coefficient of actual on calculated	0·53±0·026	0·69±0·026	0·47±0·056	
Percentage error of regression	4·9	3·7	11·9	

TABLE IV

Statistical analysis—contd.

Head	Methods					
	1	2	3	4		
				Below 50 sq. cm.	50 to 100 sq. cm.	Above 100 sq. cm.
Standard deviation per cent	5·6	7·0	9·3	3·25	1·61	1·37

It will be seen from the figures that standard deviation is greatest in method 3 and least in method 4; and further, in method 4 the error decreases with increase in leaf area. It is therefore clear that a greater precision in the measurement is possible by method 4. This feature and the ease with which the leaves can be handled and measured commend its adoption. It has been observed that for large-scale measurements of leaf areas, it was possible to complete, by the cardboard method, the measurements of as many as thirty-three plants with fifty leaves in each during a period of five hours which works out to more than five leaves per minute.

ACKNOWLEDGEMENTS

The author is indebted to Dr S. Kasinatha Ayyar for his valuable guidance in writing this paper. His thanks are also due to fieldman C. Sethumadhavamenon for his assistance throughout the work.

SUMMARY

A simple method for measuring leaf areas of cotton plants, named the cardboard method, is described. This method has been found to be easier and to consume less time without any loss in accuracy. Its special advantage is the measuring of leaves *in situ* without detaching from plants and without causing the slightest injury to them such that the progressive growth as influenced by the different treatments of an experiment could be studied in one and the same plant material.

REFERENCES

Briggs, G. E., Kidd, F. and West, C. (1920). *Ann. Appl. Biol.* **7**, 103
Frear, E. H. (1935). *Plant Phys.* **10**, 569
Gregory, F. G. (1921). *Ann. Bot.* **35**, 93
Kraemer, P. J. (1937). *Amer. J. Bot.* **24**, 375
Mitchell, J. W. (1936). *Science* **83**. 334
Vyvyan, M. C. (1924). *Ann. Bot.* **38**, 60
Watson, D. J. (1937). *J. Agric. Sci.* **27**, 474
Withrow, R. (1935). *J. Agric. Res.* **50**, 637

LINKAGE RELATIONS OF THE WHITE-POLLEN FACTOR IN ASIATIC COTTONS

BY

G. K. GOVANDE

Economic Botanist to Government, Baroda

(Received for publication on 5 April 1940)

INTRODUCTION

THE present studies were undertaken during the author's studentship period at the Institute of Plant Industry, Indore, in 1934. Preliminary work was done there but the results being inconclusive the material was carried to Baroda later in 1937. The inheritance of the white-pollen factor in a strain Cocanada 45 was shown [Ayyar and Balasubrahmanyan, 1933] to be due to a single-factor difference, the yellow colour of the pollen being dominant, and the same strain was further worked upon to find out linkage of the white-pollen factor, if any, with other factors.

MATERIAL

The strain Cocanada 45 was crossed with strains differing from it in a number of simply inherited genes with the object of discovering linkage relations of the white-pollen factor. Many strains were originally used for this purpose but only those which gave conclusive results are mentioned below with their constitution.

Strain	Constitution					
	Corolla colour	Anthocyanin pigment	Leaf shape	Lint colour	Leaf nectaries	Pollen colour
Cocanada 45	Y	R^s	l	k	ne	yp
A8 Burma laciinated . .	Y	R_s	L^L	K	Ne	Y_p
N6 multiple recessive . .	y	r_s	l	k	ne	Y_p

RESULTS

The F_1 hybrids of the crosses involving both A8 and N6 with Cocanada 45 were fully dominant for the characters concerned. The summary of the results of the same grown to F_2 and F_3 generations is presented in Table I.

The data for the pollen colour and the leaf nectaries in A8 × Cocanada 45 crosses show a significant deviation from the normal 9: 3 : 3 : 1 dihybrid ratio, indicating a linkage of the coupling phase between the two factors with a cross-over value of 18·3 per cent in the F_2 and 14·7 per cent in the F_3 generations. That the whole of the discrepancy was due to linkage and not due to any disturbance in the single factor ratios was confirmed by partitioning the χ^2 for three degrees of freedom into its components in a manner shown by Fisher [1936]. χ^2 for the linkage degree of freedom alone was found to be very large and significant in each case. As regards other characters, namely leaf shape and lint colour in the same crosses and anthocyanin pigment and

petal colour as studied in N6 × Cocanada 45 crosses, with a comparatively smaller population, the deviations from the expected ratio are not significant, thus giving no evidence of linkage between any one of these characters and pollen colour.

TABLE I

Two-factor ratios in crosses of Cocanada 45 × A 8 *and Cocanada* 45 × N 6

	White pollen and	Yellow pollen		White pollen		Total	χ^2	P
		X	x	X	x			
F_2, A8 × Cocanada 45	**Ne-ne** Obs	341	47	38	87	513	164·01	V. small
	$\mathbf{L^{L}}$-l Obs.	295	94	94	30	513	0·37	Large
	K-k Obs.	289	96	86	34	505	1·09	Large
F_3, A8 × Cocanada 45	**Ne-ne** Obs.	562	48	61	141	812	310·82	V. small
	$\mathbf{L^{L}}$-l Obs.	314	75	101	29	519	7·29	>0·05
	K-k Obs.	270	76	77	34	457	3·66	Large
F_2, N6 × Cocanada 45	$\mathbf{R^{s}}$-$\mathbf{r^{g}}$ Obs.	38	12	7	5	62	2·46	Large
	Y-y Obs.	37	14	10	1	62	2·97	Large
F_3, N6 × Cocanada 45	**R**-$\mathbf{r^{g}}$ Obs.	20	7	7	2	36	0·05	Large
	Y-y Obs.	19	8	8	1	36	1·23	Large

SUMMARY

Cocanada 45, a strain with white pollen was crossed with both A8 Burma laciniated and N6 multiple recessive in order to discover the linkage relations of the white-pollen factor in Asiatic cottons. No back-cross data are available, but other results obtained are presented here which show a clear evidence of linkage between the white pollen and leaf nectaries with cross-over values of 18·3 per cent and 14·7 per cent in the F_2 and F_3 generations respectively.

As regards other genes, namely that for petal colour, anthocyanin pigment leaf shape and lint colour the deviations from the expected ratio are not significant, indicating occurrence of free assortment, a record of equally great importance.

ACKNOWLEDGEMENTS

Thanks are due to Mr R. G. Allan for his encouragement and facilities given for carrying out this investigation ; to Mr G. S. Mulani for his help in the collection of the data and to Rao Bahadur V. Ramanatha Ayyar for the supply of the white-pollen strain.

The author is much indebted to Mr J. B. Hutchinson for his guidance in the conduct of this experiment and to Dr V. G. Panse for valuable suggestions.

REFERENCES

Ayyar, V. Ramanatha, and Balasubrahmanyan, R. (1933). *Ind. J. Agric. Sci.* **3**, 1116

Fisher, R. A. (1936). '*Statistical methods for research workers*' (6th edition) : Oliver and Boyd

A NOTE ON THE SHAPE OF BLOCKS IN FIELD EXPERIMENTS

BY

RAMJI NARAIN, D.Sc., PH.D.

AND

AZMAT SINGH

Chemical Laboratories, Agricultural Research Institute, Lyallpur

(Received for publication on 27 January 1940)

(With four text-figures)

THE success of field experiments depends not only upon the inclusion amongst treatments to be tested of all such factors upon which information is desired, but also upon the adoption of suitable forms of layout, for, as is well known, the application of even the most elaborate methods of statistical interpretation cannot overcome the disadvantages of an unsatisfactory design. There is no lack of evidence to show that soil-heterogeneity is a phenomenon of universal occurrence, and unless due consideration is paid to this factor the results of field experiments are liable to be inaccurate. There are two forms of soil-heretogeneity, viz. casual and permanent. An increase in the plot-size, maintenance of absolute uniformity in agricultural operations, correcting the surface level, etc. will remove most of the unfavourable effects of casual soil-heterogeneity. The permanent differences, irrespective of the type of crop grown, are independent of such factors, and are found to persist under all conditions. Their effects can be minimised only by adopting a suitable lay-out. In actual practice it is not uncommon to meet with both these types of fertility variations on one and the same piece of land. Examination of data from soil-uniformity trials has led a number of workers to conclude that generally speaking soil-fertility varies in particular directions. In all such cases it is a matter of considerable importance so to devise the layout that the effects of permanent differences owing to drift in soil-fertility are eliminated to as great an extent as possible. Some investigators who have devoted attention to this problem have suggested that this object can be attained by the provision of a fairly large number of replications in the trials. This, however, is not always practicable. Further, if the land acquired for providing additional replications differs considerably in fertility from that available for the original number of replications, the reduction in error aimed at by increasing the number of replications will not be proportionate. This fact has been clearly brought out by Lander, Ramji Narain and Azmat Singh [1938]. The possibility of eliminating these effects by a suitable layout of blocks and plots within blocks, however, has not received sufficient attention. It is true that the size and shape of blocks as also of plots within blocks, depend very largely upon certain practical considerations, e.g. the size and shape of the area available, the existing position of irrigation channels, roads, etc. yet even within these limitations a certain amount of choice is still available which can be exercised in a manner that is likely to increase the precision of the experiment.

A soil-uniformity trial with *chari* was conducted at Rawalpindi in *kharif* 1936. On the basis of the data obtained an attempt has been made in the present paper to present a number of alternative designs which were possible on this area and to discuss the merits of each design with a view to deciding upon the most suitable form of layout.

It is well known that the degree of precision of an experiment depends largely on the extent to which plots of as uniform a fertility as possible are included within any one block. Wishart and Sanders [1935] have discussed the merits of both square and oblong plots and, keeping practical considerations in view, have concluded that so long as areas of fairly uniform fertility can be provided for different blocks, the size and shape of the blocks and of ultimate plots become essentially a question of convenience. In other words, according to these authors, soil-uniformity within the blockexercises a far greater influence in reducing the error than the actual size or shape of plots or blocks.

In order to take away the maximum fertility differences of the land the modern field experiments require the blocks to be so laid out as to follow each other along the line of the fertility gradient. It is further emphasised that plots within any block should be as similar in fertility as possible and should lie lengthwise in the direction of greater change in soil-fertility. Further Fisher and Wishart [1930] have pointed out the necessity of having blocks as compact as possible in form. According to them long, narrow blocks are less suitable. In certain cases, however, as discussed below, greater precision is obtained, if taking into consideration the variation of soil fertility in particular directions the blocks or at least some of these are made long rather than compact.

Soil-uniformity trial data

The trial supplying the data examined in this paper was carried out on a piece of land measuring about four acres and the crop was harvested from 140 plots numbering 1, 2, 3..140, each plot being 36 ft. × 30·25 ft. or 1/40th of an acre in size and arranged in the order shown in the plan given below. The yield corresponding to each plot is also given in the plan.

		126	99	98	71	70					
127	5·7	5·6	6·5	6·2	7·2	7·4					
128	5·1	4·5	6·1	5·4	5·7	7·1					
129	4·9	4·9	5·8	4·9	5·3	6·7	43	42	15		
130	4·7	4·5	5·8	6·0	5·8	6·9	7·9	10·7	9·7	9·9	14
131	4·6	5·3	5·7	4·8	5·9	7·0	6·9	9·2	8·0	7·5	13
132	5·1	5·7	5·6	4·7	6·6	6·6	6·6	9·1	7·3	7·8	12
133	5·8	4·9	5·5	5·0	6·0	7·2	6·8	9·0	7·7	7·9	11
134	5·3	5·4	5·1	5·0	5·7	7·9	6·6	9·3	7·0	6·5	10
135	4·7	4·9	5·4	5·3	5·8	7·6	7·0	9·0	6·2	5·3	9
136	5·0	5·3	4·7	4·5	5·6	8·4	6·3	9·1	5·6	5·7	8
137	5·3	5·3	6·3	4·7	5·6	7·8	7·6	10·4	5·4	5·5	7
138	6·8	5·5	6·8	6·2	6·9	7·9	7·9	8·7	6·0	6·1	6
139	7·1	6·1	6·8	6·8	6·6	7·5	8·3	8·9	6·4	6·6	5
140	6·7	6·6	7·6	6·2	6·2	8·1	8·2	8·5	7·1	6·8	4
		113	112	85	84	57	6·5	7·3	7·6	7·0	3
							6·8	6·1	6·8	7·1	2
							6·4	6·5	6·3	6·6	1
							56	29	28		

Layout plan and yield data (maunds per 1/40th acre) of soil-uniformity crop of *chari* grown during *kharif* 1936 at the Rawalpindi Agricultural Station.

Before proceeding to discuss the data, one important point in connection with these plots, which seems to exercise a great influence on the conclusions

that may be drawn, must be mentioned. In order to supply water to the Rawalpindi Cantonment, the military authorities have constructed a number of wells from the Murree side towards the cantonment area. These wells are connected with each other by means of underground pukka channels or ducts whose level is so arranged that when the water from the last well in the cantonment area is pumped out the flow of water is automatically directed to the last well of the series. In this manner contact is maintained between the water in all the wells that go to make up the chain. A part of this water duct happens to pass beneath the piece of land on which this experiment was carried out and its direction and width is shown in Fig. 1 by two lines running parallel to each other from the north in a south-western direction. The depth of the soil lying over this duct is about 12 ft. and, as can well be imagined, this soil which had once been dug out and refilled must behave differently from the adjoining soil. About six years back, owing to the water-duct getting choked by the crumbling in of its walls, the soil above this duct was dug out and after repairing the former again put back. The fact that this soil and also that which adjoins this dug-out channel on its both sides has a different level of fertility can be seen from the soil fertility-contour map.

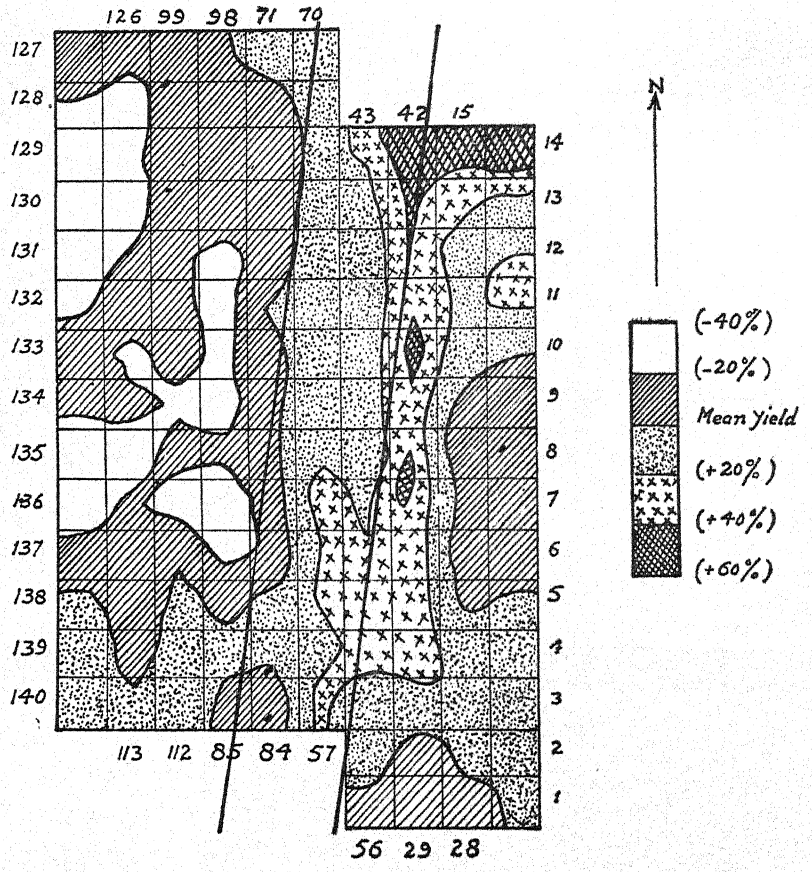


FIG. 1. Fertility contour map based on yield of *chari* (*kharif*, 1936) at Rawalpindi Agricultural Station

Discussion of results

It is clear from the contour map that soil-fertility varies much more from east to west than from north to south. This means that if the blocks are so laid out as to follow each other from east to west there is a greater possibility of the land within these blocks being more uniform than it would be if these were to follow each other from north to south. It is seen that the area affected by the water-duct which is shown in Fig. I as enclosed between two parallel lines running from north-east to south-west is characterised by a more uniform soil-fertility than the area on either side of it, particularly on the eastern side. This may be due to the fact that during the process of digging out and refilling, the soil in this area had been mixed and rendered more uniform than before. The layout of the blocks with lengths from north to south would thus seem to be more advantageous. This is further borne out when the yield data are considered after arranging them in the form of a Latin square. This can be done after excluding three rows on both the northern and southern sides of the field, leaving 100 plots to be arranged in the form of a 10 × 10 Latin square. The analysis of variance for this Latin square is given in Table I.

Table I

Analysis of variance for 10 × 10 Latin square

Source of variation	Degrees of freedom	Sum of squares	Mean square	Ratio of variances	Remarks
Rows	9	11·23	1·248 (V_1)	2·985 (V_1/V_3) 11·698 (V_2/V_1)	Significant differences between columns and rows
Columns	9	131·39	14·599 (V_2)	34·922 (V_2/V_3)	
Error	81	33·84	0·418 (V_3)	..	Column-to-column differences significantly greater than those from row-to-row
Total	99	176·46			

For $P = 0{\cdot}01$, $n_1 = 8$, $n_2 = 80$, F = 2·74

For $P = 0{\cdot}01$, $n_1 = 8$, $n_2 = 9$, F = 5·47

It is clear from the above figures that both the row-to-row and column-to-column differences are significant but the latter are significantly greater than the former, thus confirming the conclusion already drawn, viz. that in this area there is a far greater degree of variation in soil-fertility from east to west than from north to south.

Before proceeding further, it may be mentioned that two sets of experiments were intended to be laid out on this piece of land, viz. (*a*) a study of the comparative value of different types of organic manures to be applied in different amounts, and (*b*) a study of the relative value of different artificial manures

to be applied alone as well as in conjunction with green manure. There were seven treatments in the trial with organic manures and with eight replications it could be laid out in the first fifty-six plots giving eight blocks of seven plots each. The trial with artificials had fourteen treatments, and was laid out in six blocks of fourteen plots each, the plots numbering 57 to 140. The blocks in both the trials were laid out with their lengths from north to south. Owing to the greater disturbance of the soil by the water-duct on the north east corner of the land an area corresponding to eight plots in two rows was left out on the north and a corresponding area added towards the south. This course was justified when it is considered that even after the above adjustment, the fertility of plots 14, 15, 42 and 43 was the highest of any and it is likely that the area towards the north of these plots might have shown as much, if not greater, fertility. It would have been still better if these fifty-six plots could have been shifted further down by one or two rows. The differences in the fertility of the plots affected by the water-duct had been anticipated as a result of previous experience and the actual yield data obtained from this fertility trial amply confirm the anticipation.

As mentioned already, although two different sets of trials were designed to be laid out on this piece of land for the purpose of the present discussion, the entire area has been considered as one piece. Further, since it is proposed to compare blocks of different shapes, it has been decided to consider only as many plots as would permit of the formation of the most compact blocks approaching as much as possible a square in shape. If thirty-two plots be excluded as follows :—

eight in the first two rows on the south,
twelve in the last two rows on the north, and
twelve in the first column on the east,

a plot combination of 9×12 would be left. Further dividing the area into two divisions by a horizontal line between plots 8 and 9 on the east and 134 and 135 on the west, fifty-four plots will be obtained in each division. These may be divided into six blocks of nine plots each, providing six replications of nine treatments. The six blocks in the two divisions designated as A and B can be arranged in a number of ways as shown in Fig. 2.

Arrangements represented by type I above would seem to be the simplest, but the data presented show that the relative efficiency of this arrangement is the least. Fisher and Wishart [1930] favour compact blocks as compared with long and narrow ones. In the present case the blocks could be compressed to the maximum limit if the plots within each one of them are arranged in the form of a 3×3 square as in type III. This undoubtedly increases the relative efficiency considerably but this increase, except for type II (*a*), is still much less than that which is possible with the other two arrangements, viz. II (*b*) and IV. This may be due to the fact that on this piece of land, the drift of soil-fertility is from east to west, while no corresponding drift is to be seen in a vertical direction. The two types of arrangements in which six plots lie in one vertical column and the remaining three are joined to these either from the lower half or the upper half of the adjoining column (type II*a* & II*b*), while making the plots compact to a certain extent, nevertheless retain the original levels of fertility differences and therefore the reduction in error in blocks of this shape is not very great. This would indicate that making the blocks as

compact as possible without taking into consideration the variations in soil-fertility does not in all cases result in an increase in the precision of the experiment. The arrangement represented by type IV in divisions A and B is based upon due consideration of the results of the uniformity trial and combines the advantages of both compactness as well as regularity in the drift of soil-fertility. It is thus clear that in one and the same trial all the blocks need not be necessarily of the same shape.

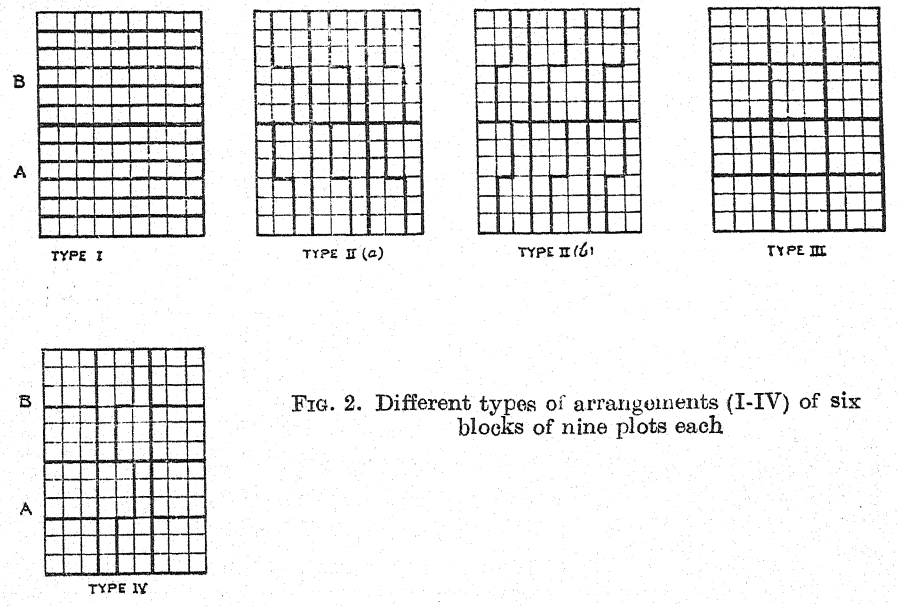


FIG. 2. Different types of arrangements (I-IV) of six blocks of nine plots each

The analyses of variance for the different types of blocks in the two divisions 'A' and 'B' are given in Table II.

TABLE II

Analysis of variance of plot yields of different types of arrangements (six blocks of nine plots each)

Type of arrangement	Source of variation	Degrees of freedom	Sum of squares	Mean square	Ratio of variances	Relative efficiency
			Division A			
I	Between blocks .	5	9·67	1·934	1·13	67·8
	Within blocks .	48	82·35	1·716		
II (*a*)	Between blocks .	5	30·89	6·178	4·85*	91·3
	Within blocks .	48	61·13	1·274		

* Significant at 1 per cent level

TABLE II—*contd.*

Type of arrangement	Source of variation	Degree of freedom	Sum of squares	Mean squares	Ratio of variances	Relative efficiency
			Division A—contd.			
II (*b*)	Between blocks .	5	45·46	9·092	9·37*	119·9
	Within blocks .	48	46·56	0·970		
III	Between blocks .	5	36·20	7·240	6·23*	100·0
	Within blocks .	48	55·82	1·163		
IV	Between blocks .	5	48·16	9·632	10·54*	127·2
	Within blocks .	48	43·86	0·914		
			Division B			
I	Between blocks .	5	1·43	0·286	0·116	37·4
	Within blocks .	48	118·27	2·464		
II (*a*)	Between blocks .	5	80·81	16·162	20·00*	113·8
	Within blocks .	48	38·89	0·870		
II (*b*)	Between blocks .	5	83·59	16·718	22·23*	122·6
	Within blocks .	48	36·11	0·752		
III	Between blocks .	5	75·46	15·092	16·37*	100·0
	Within blocks .	48	44·24	0·922		
IV	Between blocks .	5	85·03	17·006	23·55*	127·7
	Within blocks .	48	34·67	0·722		

*Significant at 1 per cent level

The above conclusion has been derived by considering the entire area as one piece of land. But, as has already been mentioned, it was proposed to lay out two different types of experiment on this land, the trials with organic manures to be confined to the first fifty-six plots and those with the artificials to the remaining eighty-four. Considering the area occupied by these plots under the two sets of trials separately, it will be interesting to see how far, by arranging the blocks in a number of ways, the above conclusions arrived at from a consideration of the entire area as a whole can be borne out with respect to each of the two pieces of land separately. The area under trial with artificials was designed to include fourteen treatments with six replications. It is possible to arrange the six blocks of fourteen plots each in a number of ways of which four types are shown in Fig. 3. The analyses of variance of the four types of arrangements are given in Table III.

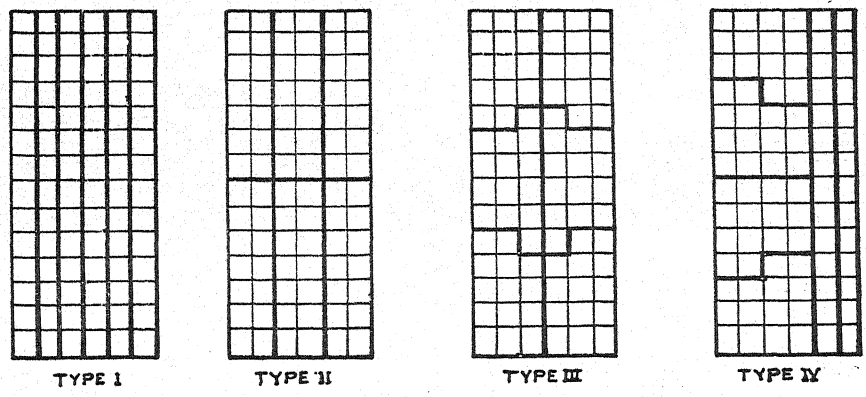


FIG. 3. Different types of arrangements (I-IV) of six blocks of 14 plots each (artificial series)

TABLE III

Analysis of variance of plot yields of different types of arrangements (six blocks of fourteen plots each)

Type of arrangement	Source of variation	Degrees of freedom	Sum of squares	Mean square	Ratio of variances	Relative efficiency
I	Between blocks	5	43·70	8·740	19·00*	155·0
	Within blocks	78	35·85	0·460		
II	Between blocks	5	32·62	6·520	10·83*	118·5
	Within blocks	78	46·93	0·602		
III	Between blocks	5	23·96	4·790	6·72*	100·0
	Within blocks	78	55·59	0·713		
IV	Between blocks	5	56·71	11·340	38·84*	244·2
	Within blocks	78	22·84	0·292		

* Significant at 1 per cent level

It will be seen that type III represents the most compact form of blocks which could be arranged on this piece of land and type I the least. In type IV the compactness has been introduced after taking into consideration the drift of soil-fertility and thus, of the six blocks, whereas four are as compact as possible, the remaining two are long and narrow ones with their lengths running parallel to the drift of soil fertility. The remaining (type II) gives some compactness but not as much as type III.

The figures for relative efficiency given in the last column (Table III) show that whereas type III is the most compact form of arrangement yet its efficiency is the least of all. Type IV has proved to be the most efficient of all the arrangements considered and as compared with the most compact form it is nearly two-and-a-half times more efficient.

Considering the area reserved for trials with organic manures the three types of arrangements considered are given in Fig. 4.

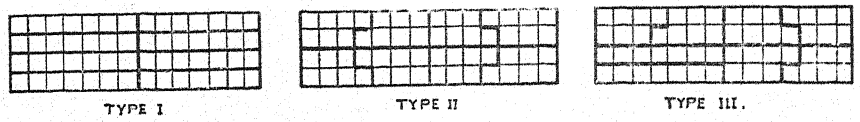


FIG. 4. Different types of arrangements (I-III) of eight blocks of seven plots each (organic series)

The analyses of variance for these three types are given in Table IV.

TABLE IV

Analysis of variance of plot yields of different types of arrangements (eight blocks of seven plots each)

Type of arrangement	Source of variation	Degrees of freedom	Sum of squares	Mean square	Ratio of variance	Relative efficiency
		Organic series				
I	Between blocks	7	38·13	5·450	4·68*	84·7
	Within blocks	48	55·90	1·165		
II	Between blocks	7	46·68	6·670	6·76*	100
	Within blocks	48	47·35	0·987		
III	Between blocks	7	63·72	9·100	14·42*	156·4
	Within blocks	48	30·31	0·631		

* Significant at 1 per cent level

Here also the conclusions arrived at from a consideration of the area reserved for trials with artificial manures are fully borne out. When all the blocks are kept long and narrow, the relative efficiency is the lowest. On the other hand when all these eight blocks are made compact the efficiency increases appreciably. The greatest increase, however, takes place when the two blocks affected by the water-duct are kept long and narrow and the remaining six made compact.

The above discussion clearly shows that to increase the precision of the experiment compactness of the blocks is of use only when it results in making the area within the blocks more uniform than it would be otherwise. If by making the blocks compact the area included within any one of these becomes more heterogeneous than otherwise, it is better not to attempt such a compression. It is no disadvantage if the shape of all the blocks included in a trial is not similar. Whatever may be the shape of the blocks, the only point to be aimed at should be that the land within the blocks is as uniform as possible.

SUMMARY

1. The results of a soil-uniformity trial with *chari* grown at the Rawalpindi Agricultural Station have been presented and considered in a number of ways.

2. Fertility contours indicating variations in soil-fertility met with on this piece of land have been drawn.

3. The drift of soil-fertility indicated by the fertility contours has been confirmed by analysing the plot yields in the form of a Latin square.

4. The suggestion that the precision of the experiment could be considerably increased if the blocks were made as compact as possible has been examined in detail and it has been shown that compactness does not always result in the increase in precision.

5. The advantage accruing from the provision of compact blocks depends upon the fact that the land within these is likely to be more uniform than that within a block which is long and narrow in shape. This, however, is not always the case. If, therefore, by making the blocks compact different levels of soil-fertility are introduced within any one of them the advantages of compactness will be considerably offset.

6. It has been shown that the greatest precision in the conduct of the trial is obtained by keeping the land within the blocks as uniform as possible irrespective of the shape of the individual blocks.

REFERENCES

Fisher, R. A. and Wishart, J. (1930). *Imp. Bureau Soil Sci. Tech. Comm.* No. **10**

Lander, P. E.; Narain, R. and Singh, A. (1938). *Ind. J. Agric. Sci.* **8**, 271

Wishart, J. and Sanders, H. G. (1935). *'Principles and practice of field experiment'*

A NOTE ON THE DESIGN AND ANALYSIS OF COMPACT EXPERIMENTS WITH THREE OR FOUR RESTRICTIONS

BY

P. V. KRISHNA IYER, M.A.

AND

SUDHIRCHANDRA SEN, M.Sc.

Imperial Agricultural Research Institute, New Delhi

(Received for publication on 25 March 1940)

Introduction

PATERSON [1933] in dealing with the modifications of Latin square gives a type of layout, called ' magic square', in which every treatment occurs once in each row, once in each column and once in each quarter. ' The statistical methods ', he says, ' are the same as those described for the randomised block or Latin square layout. The sums of squares due to similar groups of plots, e.g. blocks, rows, columns, sections, treatments, etc., are subtracted from the total sum of squares for all plots, leaving a residual sum of squares and the residual number of degrees of freedom on which the measure of significance depends '. The method given by Paterson for the analysis of compact experiments involving more than two restrictions is too brief and is not clear regarding the orthogonal aspects of the various items involved in the analysis of variance of such experiments. This note illustrates the method of analysis for such layouts.

Material

A manurial experiment, consisting of twelve treatments, each replicated six times and laid out in a compact block in such a way as to effect elimination for soil-heterogeneity in three different ways, has been utilised for the purpose of illustration. The experiment was conducted in *kharif* 1939, and maize was grown to see the manurial effect.

The plan of the layout together with the yield of corn and the three restrictions imposed on the same layout are given below :—

C 18·51	K 25·46	A 21·60	B 23·91	E 25·46	F 26·23	D 22·63	G 20·57	L 21·60	J 15·43	I 18·77	H 18·26
F 19·03	L 25·71	I 25·20	D 26·74	J 30·08	K 19·80	B 22·63	H 23·14	G 22·63	A 18·00	E 14·91	C 18·77
E 16·46	H 21·86	J 30·86	G 24·68	C 23·91	I 22·88	L 27·26	A 17·48	F 19·28	D 17·48	B 17·74	K 16·46
B 17·36	D 25·71	K 31·75	F 22·37	H 21·08	A 24·17	J 25·71	E 24·43	C 20·31	I 21·08	L 21·86	G 14·66
G 21·86	J 24·68	L 21·60	C 23·40	D 16·46	B 18·00	K 27·90	I 19·03	H 22·88	E 15·43	A 12·60	F 20·06
I 20·57	A 15·68	E 13·88	H 17·23	L 13·63	G 19·03	C 21·08	F 14·40	K 20·06	B 11·44	J 17·74	D 18·51

Plan of the layout and yield of corn in lb.

C	K	A	B	E	F	D	G	L	J	I	H	
F	L	I	D	J	K	B	H	G	A	E	C	} a
E	H	J	G	C	I	L	A	F	D	B	K	
B	D	K	F	H	A	J	E	C	I	L	G	
G	J	L	C	D	B	K	I	H	E	A	F	} b
I	A	E	H	L	G	C	F	K	B	J	D	

Arrangement I

c				d				e			
C	K	A	B	E	F	D	G	L	J	I	H
F	L	I	D	J	K	B	H	G	A	E	C
E	H	J	G	C	I	L	A	F	D	B	K
B	D	K	F	H	A	J	E	C	I	L	G
G	J	L	C	D	B	K	I	H	E	A	F
I	A	E	H	L	G	C	F	K	B	J	D

Arrangement II

C	K	A	B	E	F	D	G	L	J	I	H
F	L	I	D	J	K	B	H	G	A	E	C
E	H	J	G	C	I	L	A	F	D	B	K
B	D	K	F	H	A	J	E	C	I	L	G
G	J	L	C	D	B	K	I	H	E	A	F
I	A	E	H	L	G	C	F	K	B	J	D

Arrangement III

METHOD OF ANALYSIS

The sums of squares for blocks for arrangements I and II shown above are calculated separately in the usual way, each having five degrees of freedom. The sum of squares for blocks for arrangement III is not orthogonal with those for I and II. On a careful examination, it will be found that the sum of squares for arrangement III includes portions of the sums of squares which have already been included in arrangements I and II, viz. sum of squares for sections *a* and *b* and sum of squares for sections *c*, *d* and *e* respectively shown in the

above figures. Thus the actual elimination for soil-heterogeneity effected by imposing the third restriction is 337·2199 (total s. s. for III)—56·4985 (s. s. for sections *a* and *b*)—255·5508 (s. s. for sections *c*, *d* and *e*)=25·1706 with 5—(1+2) or 2 degrees of freedom. The sum of squares for treatments is calculated in the usual way.

The final table of the analysis of variance is as follows.

Analysis of variance

Variance due to	Degrees of freedom	Sum of squares	Mean square	S_1^2/S_2^2
Restriction I	5	252·5619	..	..
Restriction II	5	304·8828	..	..
Restriction III	2	25·1706	..	..
Treatments	11	227·5826	20·6893	1·873
Residual error	48	530·1893	11·0456	..
Total	71	1340·3872		

Thus the effect of treatments can be judged with greater precision in this modified layout than in the ordinary randomized block layouts.

In the example cited above, three restrictions have been imposed on the layout. Another layout with four restrictions is given below.

f	H	G	I	J	L	K	B	A	D	C	F	E
	B	A	D	C	F	E	H	G	I	J	L	K
g	F	E	K	L	D	C	I	J	B	A	H	G
	I	J	A	B	H	G	E	F	L	K	D	C
h	D	C	E	F	B	A	L	K	G	H	J	I
	K	L	G	H	J	I	D	C	E	F	B	A

a, *b*

Arrangement I

c				*d*				*e*			
H	G	I	J	L	K	B	A	D	C	F	E
B	A	D	C	F	E	H	G	I	J	L	K
F	E	K	L	D	C	I	J	B	A	H	G
I	J	A	B	H	G	E	F	L	K	D	C
D	C	E	F	B	A	L	K	G	H	J	I
K	L	G	H	J	I	D	C	E	F	B	A
		i				*j*					

Arrangement II

H	G	I	J	L	K	B	A	D	C	F	E
B	A	D	C	F	E	H	G	I	J	L	K
F	E	K	L	D	C	I	J	B	A	H	G
I	J	A	B	H	G	E	F	L	K	D	C
D	C	E	F	B	A	L	K	G	H	J	I
K	L	G	H	J	I	D	C	E	F	B	A

Arrangement III

H	G	I	J	L	K	B	A	D	C	F	E
B	A	D	C	F	E	H	G	I	J	L	K
F	E	K	L	D	C	I	J	B	A	H	G
I	J	A	B	H	G	E	F	L	K	D	C
D	C	E	F	B	A	L	K	G	H	J	I
K	L	G	H	J	I	D	C	E	F	B	A

Arrangement IV

The analysis is done on the same lines as the one with three restrictions. The sums of squares for arrangements I, II and III are calculated in the same way as discussed in the previous example. The sum of squares for arrangement IV is equal to total sum of squares for IV—sum of squares for sections f,g, and h—sum of squares for sections i and j, the degrees of freedom being 5—(2+1) or 2. The analysis of variance table showing the degrees of freedom for the various items is given below :—

Variance due to	Degrees of freedom
Restriction I	5
Restriction II	5
Restriction III	2
Restriction IV	2
Treatments	11
Residual error	46
Total	71

Maximum number of restrictions and designs

It will be of interest to note that the maximum number of restrictions that can be imposed on a certain layout is dependent on the number of replications and the number of treatments. The following table gives the maximum number of restrictions with different numbers of replications and treatments, each block being a compact rectangular unit.

Number of treatments	Number of replications	Maximum number of restrictions
4	4	3
6, 12, 18, 24, 30, 36	6	4

The lay-out for four treatments, replicated four times with three restrictions, can be formed without much difficulty, and the plan below represents a design involving six treatments, each replicated six times, with four restrictions.

a	b	c	d	e	f
d	e	f	a	b	c
c	f	b	e	a	d
e	a	d	c	f	b
b	c	a	f	d	e
f	d	e	b	c	a

Plan showing six treatments with four restrictions

For an experiment involving six treatments, it is possible to have $\underline{|6} \times 1936$ designs with four restrictions. The method of forming any one of them is described below. For convenience, this method, which is applicable to all the cases, is discussed with special reference to the arrangement shown in the plan above. The six treatments which are represented by the letters a, b, c, d, e and f can be arranged in $\underline{|6}$ ways, and the first row can be any one of them. Taking the first row as $a\ b\ c\ d\ e\ f$, the second row can be arranged in 2^4 ways after taking into consideration the fact that the letters d and c should not occupy the third and fourth columns of the second row. Out of these 2^4 arrangements, let us take the one shown in the second row of the above plan, viz. $d\ e\ f\ a\ b\ c$. When once the first two rows are fixed, the columns 1 and 2, 3 and 4, and 5 and 6 of the third row can be filled up only by three specific pairs of letters. In the plan shown above, they are $c\ f$, $b\ e$ and $a\ d$, and it is evident that they can be permuted in 2^3 ways. Now coming to the fourth row, the first and the second halves are $e\ a\ d$ and $c\ f\ b$. Since a or d and c or f cannot occupy the first and the sixth columns respectively, e and b are fixed at those places. In the general case, two columns of the fourth row, one on each half of the row are fixed. After fixing e and b, a and d (of the fourth row) can be put in 2 ways, and one of the arrangements, viz. $a\ d$ is taken here. The letters coming below e and b in the two remaining rows can be taken in 4 ways, and in this particular case, we have taken $b\ f$ and $e\ a$. The letters at the second and third columns of the fifth and sixth rows, viz. $c\ a$ and $d\ e$ can be filled up easily at this stage, and the remaining six letters, viz. $c\ f$, $f\ d$ and $b\ c$ get automatically fixed satisfying the required conditions.

The design for the layout involving twelve treatments can be had from the same layout by replacing each of the letters a, b, c, d, e and f by a_1, a_2;

b_1, b_2 ; c_1, c_2 ; d_1, d_2 ; e_1, e_2 and f_1, f_2 respectively, $a_1, a_2 \ldots\ldots f_1, f_2$ being the twelve treatments. It may be mentioned that the treatments within each of the six groups (i.e., a_1, a_2 ; b_1, b_2 ; $\ldots\ldots f_1, f_2$) should be randomized separately.

The layouts for the other experiments involving eighteen, twenty-four, thirty, thirty-six, etc. treatments can be formed on the lines indicated above by dividing them into groups of three, four, five, six, etc. treatments respectively.

SUMMARY

The paper deals with the design and the method of statistical analysis of compact experiments with three and four restrictions. It is not recommended that experimenters should adopt such designs in general, but in cases where an increased precision is expected by such a layout, the correct analysis should be as indicated in this paper.

REFERENCE

Paterson, D. D. (1933). *Trop. Agric.* **10**, 303-17

NOTES

NOTICE NO. F. 1-9 (5)/40-A, DATED THE 19 JULY 1940 ISSUED BY THE GOVERNMENT OF INDIA, IN THE DEPARTMENT OF EDUCATION HEALTH AND LANDS

IT is notified for general information that an Order similar to the Importation of Plants (Amendment) Order of 1940, dated April 10, 1940, issued by the Ministry of Agriculture and Fisheries, London, which was published with this Department notification No. F. 1-9 (3)/40-A., dated the 29th May, 1940, has been issued by the Secretary of State for Scotland and came into operation on the 1st May, 1940.

NOTICE 2 OF 1940—APRIL TO JUNE 1940

THE following plant quarantine regulations and import restrictions have been received in the Imperial Council of Agriculture Research. Those interested are advised to apply to the Secretary, Imperial Council of Agricultural Research, New Delhi, for loan.

I. List of United States Department of Agriculture, Bureau of Entomology and Plant Quarantine Services and Regulatory Announcements

1. *Quarantine and other official announcements* :—
   (*i*) Mexican Fruitfly Quarantine—modification of regulations.
   (*ii*) Pink Bollworm Quarantine—modification of regulations.
2. *Summaries of plant quarantine import restrictions* :—
   (*i*) Union of South Africa—restrictions on the importation of potatoes.
   (*ii*) United Kingdom of Great Britain—revision of the digest.
   (*iii*) Republic of Cuba—White-fringed beetle—importation of certain products prohibited from infested areas.
   (*iv*) Republic of Mexico—Amendment to Exterior Quarantine No. 12. Abrogated—Alfalfa seed from Muma country, Arizona.
   (*v*) Kingdom of Egypt—importation of certain fruits and plants prohibited.
3. *Service and Regulatory Announcements.*—Index, 1938.

II. Other Regulations.

1. *Iraq.*—Importation of Plants Law No. 31 for 1938.
2. *Colony and Protectorate of Kenya* :—
   (*i*) Plant Protection Ordinance, 1937—Rules.
   (*ii*) Government Notices Nos. 969 & 970.
   (*iii*) Amendment of Schedules.

PRIZE FOR A DESIGN OF AN IMPROVED AGRICULTURAL IMPLEMENT OR MACHINE

IN order to encourage inventors to improve existing implements of cultivation and to design new implements and machines better suited to Punjab conditions and within the power of the average cultivator to purchase, the Punjab Government has instituted a scheme of prizes for a suitable design of a particular improved agricultural implement or machine. These prizes are open to all (including Government servants) irrespective of nationality.

Last year a prize of Rs. 3,000 was offered for a simple and cheap Winnower to separate *bhusa* from grain after the wheat crop has been trampled out by bullocks. None of the entries received in competition was considered to be free from defects, but for the most promising entry, in the opinion of the Judging Committee, Government awarded a sum of Rs. 1,000 to Messrs. H. T. Satterford, Superintendent of Workshops, Punjab College of Engineering and Technology, Moghalpura, Lahore, and Lekh Singh, Overseer, Punjab Agricultural Engineering Section, Lyallpur, for their design of pedaldriven machine. This design is now being improved and in due course it is intended to arrange for the manufacture of the machine on a mass-production basis.

This year another prize of Rs. 3,000 has been advertised for a suitable design of a cheap, bullock-drawn, automatic, multiple-row sowing drill, entries for which should reach the Director of Agriculture, Punjab, by the 30 September 1940 at latest.

REVIEW

The breeding of herbage plants in Scandinavia and Finland. (*Joint Publication No. 3 of the Imperial Agricultural Bureaux.*) Pp. 124. Price 4*s*.

ARRANGEMENTS have been made between the various Imperial Agricultural Bureaux whereby any publication upon the preparation of which two or more Bureaux collaborate shall be included in a new series entitled Joint Publications. It has been decided to regard the earlier Joint Publications on '*Vernalization and phasic development of plants*' and '*Erosion and soil conservation*', as Nos. 1 and 2 in this series. Other Joint Publications produced in recent years but already out of print have not been given numbers in the series.

The Imperial Bureau of Plant Breeding and Genetics and the Imperial Bureau of Pastures and Forage Crops have now produced Joint Publication No. 3, entitled '*The breeding of herbage plants in Scandinavia and Finland*'. It is a symposium consisting of a series of articles by acknowledged specialists in the respective countries. G. Nilsson-Leissner, F. Nilsson, E. Akerberg and R. Torssell contribute articles on work in Sweden. H. N. Frandsen, H. Wexelsen and O. Pohjakallio on Denmark, Norway and Finland respectively.

Each article reviews recent developments in the countries concerned, including details of the most recent improved strains of grasses, clovers and lucerne, and the methods used in producing them, as well as a contribution on the application of cytology to herbage plant breeding. The articles vary from 5 to 35 pages in length and are mostly quite detailed, each being provided with a mass of tabular data and selected bibliographies. The Scandinavian countries are recognized authorities on grassland and breeding problems and the bulletin provides an invaluable outline of achievements up to date. This is made specially clear by a useful summary of the entrie contents of the bulletin which appears at the beginning, before the presentation of the individual articles. Another useful feature is the provision of a list of addresses of the research stations concerned and of maps illustrating their locality.

The bulletin covers 124 pages and is obtainable from either Bureau at the moderate price of 4*s*. Standing orders for Joint Publications should be placed with the Secretary, Imperial Agricultural Bureaux, 2 Queen Anne's Gate Buildings, London, S. W. 1. Wherever any Empire country orders bulk supplies direct from the Bureau in one order (i.e. 50 copies or more) a discount of 25 per cent will be allowed.

GIPD—132 1CofAR—12-10-40—750.

ORIGINAL ARTICLES

THE GENUS *FUSARIUM*

V. *FUSARIUM UDUM* BUTLER, *F. VASINFECTUM* ATK. AND *F. LATERITIUM* NEES VAR. *UNCINATUM* WR.

BY

G. WATTS PADWICK

Imperial Mycologist, Imperial Agricultural Research Institute, New Delhi

(Received for publication on 16 April 1940)

(With Plates XXXIX-XLI)

INTRODUCTION

IN the preceding paper of this series [Padwick, Mitra and Mehta, 1940] it was shown that a considerable number of isolates of *Fusarium* causing wilt of cotton (*Gossypium* sp.), pigeon-pea (*Cajanus cajan*) and sunn-hemp (*Crotalaria juncea*) are highly specialised as regards their host relations. It was early appreciated by the author that to have a sound understanding of the genus *Fusarium* the first essential is the systematic study under defined conditions of a large number of isolates, combined, where possible, with pathogenicity tests. The isolates referred to in the preceding paper formed the material for a study, in a systematic manner, of the morphology and cultural characters of these wilt-causing organisms.

CULTURAL CHARACTERS OF THE WILT-CAUSING FUNGI

The fungi were grown on the following media :—

(1) Potato dextrose agar, 2 per cent [Wollenweber ***et al.***, 1925]
(2) Brown's agar [Brown, 1925]
(3) Brown's starch agar [Brown, 1925]
(4) Steamed rice [Wollenweber *et al.*, 1925]

All the cultures used in the pathogenicity test described in Part IV of this series were grown on agar slants of the above media, in triplicate, at 30°C. The work was done concurrently with starting the pathogenicity test. As it was seen that some of the cultures were non-pathogenic or failed to produce wilt, the number of cultures was reduced for the second study of cultural characters, at 20°C.

Observations on the colours produced in the aerial mycelium and on the surface of the substrate, or ' stroma ', were made on the 10th day and again on the 20th day of growth. The remaining notes were made on the 21st to 24th days.

Nothing would be gained by giving here all the data accumulated, but since a standard method of recording has been established for all *Fusarium* cultural studies, this may be briefly described. Standard typed forms are used, with a space for notes on every character commonly used in identifying *Fusaria*. In this way only is it possible to escape the criticism that can be

justly levelled against a great deal of the taxonomic work on this genus—namely, that certain characters which the worker may happen to think unimportant for the particular species concernedare neglected. Each character, such as colour of aerial mycelium, colour of surface of substrate, abundance of aerial mycelium, sclerotia, type of fruiting structures, type of conidia in pionnotes or sporodochia, type of conidia in aerial mycelium, etc. is recorded separately for each culture. The observations on all the cultures in the experiment, and on all the media, are recorded for one character at a time, and the next character is disregarded until the previous one has been completed for all the cultures. Thus the characters which have to be described in arbitrary terms are fairly comparable for each culture in the experiment and such terms as ' few ', ' abundant ', ' thin ', ' thick ', ' distinct ', ' indistinct ', ' rough', ' smooth ', ' warty ', etc. have a real significance, the personal factor being minimised as far as possible. Colours are all recorded according to the nomenclature of Ridgway [1912]. Conidial characters are examined in water mounts at a magnification of 600. In most cases the descriptions of the spores are accompanied by rough sketches, which are especially useful in indicating the degree of curvature. In cases where chlamydospores or other structures are not found, it is usual to examine two or three slides from each tube of the triplicate series before recording the structures as absent. It is usual to record the colours, the abundance of aerial mycelium, the presence or absence of sclerotia, and the type of chlamydospores on all media, but the characters requiring minute microscopic examination, chiefly the kinds of conidia, cannot always be described thus, and in this case it is the practice to complete the data for potato dextrose agar at least, as this medium has been found rather more reliable than the others, being the one most commonly associated with ' Normkulture '. Brown's media are often found disappointing in this respect.

In Table I are recorded in the most concise manner possible all the characters in which the various wilt fungi differed appreciably. The identity of each culture as *Fusarium udum* Butler (*F. Butleri* Wr.) [Butler, 1910] or *Fusarium vasinfectum* Atk. [Atkinson, 1892, with the help of the emended descriptions of Wollenweber and Reinking, 1935] may be concluded without great difficulty from this table.

Fungi causing cotton wilt

F 25.—Both in spore shape (tapering to a point or rounded) and colour on rice (dull violet black with potassium hydroxide and deep hellebore red with hydrochloric acid) this culture is typical of *Fusarium vasinfectum.*

F 147.—The spores of this culture are again typical of *Fusarium vasinfectum.* There is a slight drabness of colour not quite normal for this species.

Fungi causing pigeon-pea wilt

F 2.—With its hooked macrospores borne in a pionnotal slime, and its brilliant yellow and orange hues on rice, this fungus is extraordinarily reminiscent of *F. udum* as described by Butler, but has no true chlamydospores.

ptation of spores on per cent P. D. A. at 30°C.	Apices of long spores at 30°C.	Colours on rice at 30°C.	Sporing structures on 2 per cent P. D. A. at 30°C.	Media with chlamydospores at 30 °C. (terminal or intercallary (Tor I). Abundance)
0 -3 on rice)	Tapering to point or rounded	Perilla purple	No characteristic sporing structures	P. D. A. (T. and I. few) Brown's agar (T. and I. few)
0—1 -2 on Brown's starch ar)	.....	Dresden brown	Do.	Brown's starch agar (T. and I rare) P. D. A.) (T. and I. moderate) Brown's agar (T. and I. moderate)
0	.....	Picric yellow and carnelian red	Do.	Brown's starch agar (I. rare)
0—5	Sharply pointed, hooked foot-celled	Cinnamon brown and hydrangea pink	Thin pionnotal layer	None... Hyphal swellings only observed on Brown's starch agar P. D. A. (T. and I. moderate)
0—1 res very rare)	.....	Cinnamon brown and pale vinaceous pink	No characteristic sporing structures	Hyphal swellings only on Brown's agar and Brown's starch agar P. D. A. (T. and I. rare)
0	.....	Picric yellow and apricot orange	Do.	Brown's starch agar (T. and I. few) P. D. A. (T. and I. moderate)
0—3	Rounded, often bent	Do.	Pale pinkish cinnamon pionnotal slime	P. D. A. (T. and I. moderate)
0—3	Do.	Do.	Do.	P. D. A. (T. and I. moderate)
0—3	Do.	Do.	Do.	Brown's starch agar (T. rare) Hyphal swellings only on Brown's agar and Brown's starch agar
0—3	Do.	Do.	Do.	Hyphal swellings only on Brown's agar
0—3	Do.	Do.	Do.	Do.
0—3	Hooked	Do.	Tilleul buff pionnotal slime	None.
0 septate on Brown's)	.....	Cream buff, apricot buff, apricot orange and chestnut brown	Pale pinkish cinnamon pionnotal slime	Do.
0	.....	Do.	Do.	P. D. A. (T. and I. few). Brown's starch agar (T. rare)
0 septate on Brown's)	.....	Pale ochraceous buff, apricot orange and chestnut brown	Do.	None.
0	.....	Do.	Do.	Brown's agar (T. and I. moderate)

TABLE I

Morphological and cultural characters of fungi causing wilt of cotton, pigeon-pea and sunn-hemp

Culture	Host plant	Sclerotia at 20°C.	Septation of spores on 2 per cent P. D. A. at 20°C.	Apices of long spores at 20°C.	Colours on rice at 20°C.	Colours on rice with 2 per cent KOH at 20°C.	Colours on rice with 2 per cent HCl at 20°C.	Sporing structures on 2 per cent P. D. A. at 20°C.	Media with chlamydospores at 20°C. (Terminal or intercallary (tor I). Abundance)	Sclerotia at 30°C.	Septation of spores on 2 per cent P. D. A. at 30°C.	Apices of long spores at 30°C.	Colours on rice at 30°C.	Sporing structures on 2 per cent P. D. A. at 30°C.	Media with chlamydospores at 30 C. (terminal or intercallary (For I). Abundance)
F 25	Cotton	None	0—6	Tapering to point	Dark hellebore red and hyssop violet	Dull violet black	Deep hellebore red	No characteristic sporing structures, but pinkish vinaceous spore masses on other media	Brown's agar (T. and I. moderate) Brown's starch agar (I. rare)	None	0 (0—3 on rice)	Tapering to point or rounded	Perilla purple	No characteristic sporing structures	P. D. A. (T. and I. few) Brown's agar (T. and I. few) Brown's starch agar (T. and I rare)
F 147	Do.	On rice. Up to 2 mm. diameter. Blackish brown.	0 (0—3 on rice)	(On rice, bluntly pointed)	Light brownish drab	Light brownish drab	Deep purple drab	No characteristic sporing structures	P. D. A. (T. and I. moderate). Brown's agar (T. and I. moderate). Brown's starch agar (I. few). Rice (T. and I. abundant)	Do.	0—1 (0—2 on Brown's starch agar)	.....	Dresden brown	Do.	P. D. A.) (T. and I. moderate) Brown's agar (T. and I. moderate) Brown's starch agar (I. rare)
F 2	Pigeon-pea	None	0—3	Hooked	Barium yellow and apricot orange	Barium yellow and apricot orange	Barium yellow and apricot orange	Pale plonnotal slime	None. Hyphal swellings only observed on Brown's agar and potato dextrose agar	Do.	0	.....	Picric yellow and carnelian red	Do.	None.. Hyphal swellings only observed on Brown's starch agar
F 3	Do. ?	.....	...	.....	.....					Do.	0—5	Sharply pointed, hooked foot-celled	Cinnamon brown and hydrangea pink	Thin plonnotal layer	P. D. A. (T. and I. moderate) Hyphal swellings only on Brown's agar and Brown's starch agar
F 4	Do. ?	.....	...	.....	.....					Do.	0—1 (Spores very rare)	.....	Cinnamon brown and pale vinaceous pink	No characteristic sporing structures	P. D. A. (T. and I. rare) Brown's starch agar (T. and I. few)
F 5	Do.	None	0—4	Rounded, rarely slightly hooked	Light seal brown, mars violet, hazel	Taupe brown	Dark livid brown	No characteristic sporing structures	P. D. A. (T. and I. few). Hyphal swellings only observed on Brown's agar and rice	Do.	0	.....	Picric yellow and apricot orange	Do.	P. D. A. (T. and I. moderate)
F 6	Do.	Do.	0—5	Hooked	Sea-shell pink and naphthalene yellow	Sea-shell pink and naphthalene yellow	Sea-shell pink and naphthalene yellow	Vinaceous cinnamon plonnotal slime	None	Do.	0—3	Rounded, often bent	Do.	Pale pinkish cinnamon plonnotal slime)	P. D. A. (T. and I. moderate)
F 7	Do.	Do.	0—3	Do.	Trace of naphthalene yellow	Trace of naphthalene yellow	Trace of naphthalene yellow	Some isolated hydrangea pink spore masses	Do.	Do.	0—3	Do.	Do.	Do.	P. D. A. (T. and I. moderate) Brown's starch agar (T. rare)
F 10	Do.	Do.	0—1	Do.	Naphthalene yellow	Naphthalene yellow	Naphthalene yellow	No characteristic spore masses, but some isolated salmon-buff spore masses on other media	Do.	Do.	0—3	Do.	Do.	Do.	Hyphal swellings only on Brown's agar and Brown's starch agar
F 11	Do.	Do.	0—3	Do.	Barium yellow and apricot orange	Barium yellow and apricot orange	Barium yellow and apricot orange	Abundant salmon-buff spore masses	P. D. A. (T. and I. abundant). Hyphal swellings only on Brown's agar and Brown's starch agar	Do.	0—3	Do.	Do.	Do.	Hyphal swellings only on Brown's agar
F 12	Do.	Do.	1—5	Do	Naphthalene yellow	Naphthalene yellow	Naphthalene yellow	Do.	Hyphal swellings only on P. D. A. and Brown's agar	Do.	0—3	Do.	Do.	Do.	Do.
F 59	Do.	Do.	0—6	Do.	Citron yellow apricot orange, anthracene purple	Citron yellow, apricot orange, anthracene purple	Citron yellow, apricot orange, anthracene purple	Ivory yellow spore masses	P. D. A. (I. few). Rice (T. and I. few)	Do.	0—3	Hooked	Do.	Tilleul buff plonnotal slime	None.
F 137	Do.	On P. D. A. Up to 5 mm. diam. Covered with white mycelium	0—3	Do.	Barium yellow, apricot buff, naphthalene violet, chestnut brown	Barium yellow, apricot buff and dull violet black	Barium yellow, apricot buff, naphthalene violet, chestnut brown	Vinaceous pink spore masses	P. D. A. (T. and I. few)	Do.	0 (0—1 septate on Brown's agar)	.....	Cream buff, apricot buff, apricot orange and chestnut brown	Pale pinkish cinnamon plonnotal slime	Do.
F 139	Do.	Do.	0—3	Do.	Anthracene purple	Dull violet black	Anthracene purple	Salmon buff spore masses	Brown's starch agar (T. and I. abundant). Hyphal swellings only on Brown's agar.	Appeared to be forming pale fleshy sclerotia on rice	0	.....	Do.	Do.	P. D. A. (T. and I. few). Brown's starch agar (T. rare)
F 164	Do.	None	0—1 (0—3 rice)	(Hooked on rice)	Vinaceous and dark mineral red	Dull violet black	Vinaceous and dark mineral red	Ochraceous buff spore masses	P. D. A. (T. and I. moderate). Brown's starch agar (T. and I. moderate). Rice (T. and I. abundant). Hyphal swellings only on Brown's agar.	None	0 (0—1 septate on Brown's agar)	.....	Pale ochraceous buff, apricot orange and chestnut brown	Do.	None.
F 165	Do.	On P. D. A. Up to 5 mm. diam. Covered with white mycelium	0—3	Hooked	Amber yellow, apricot orange, citron yellow, corinthian pink	Amber yellow, apricot orange, citron yellow, corinthian pink.	Amber yellow, apricot orange, citron yellow, corinthian pink	Light vinaceous cinnamon spore masses	P. D. A. (T. and I. few)	Appeared to be forming large pale fleshy sclerotia on rice	0	.....	Do.	Do.	Brown's agar (T. and I. moderate)

F 5.—The spores of this fungus are not always hooked and it has none of the characteristic pionnotes of *F. udum*. Its brown hues on rice at 20°C. are not typical of *F. udum*, but at 30°C. on rice it has the unmistakable picric yellow and apricot orange colours. The terminal and intercallary chlamydospores are true to type.

F 6.—The hooked spores borne in vinaceous cinnamon or pale pinkish cinnamon pionnotal slime, as well as the picric yellow and apricot orange colours on rice at 30°C. give this fungus the unmistakable appearance of *F. udum*. The chlamydospores are true to type.

F 7.—Typical *F. udum*.

F 10.—Typical *F. udum* except in lacking chlamydospores.

F 11.—Typical *F. udum*.

F 12.—Typical *F. udum* except in lacking chlamydospores.

F 59.—The hooked spores, the colour on rice at 30°C. and the chlamydospores, are typical of *F. udum*. The pionnotes are paler. A striking characteristic is the production of an anthracene purple pigment on rice at 20°C.

F 137.—The hooked spores in pionnotes and the chlamydospores are typical of *F. udum*. The cream buff and chestnut brown colours on rice at 30°C. and the naphthalene violet colour at 20°C. do not conform with the original description of *F. udum*.

F 139.—True to *F. udum* in all other respects, the culture produces a striking anthracene purple pigment on rice at 20°C. becoming dull violet black with potassium hydroxide and unaltered with dilute hydrochloric acid.

F 164.—Closely resembles F 139.

F 165.—Resembles F 139 but produces corinthian pink colour instead of anthracene purple on rice at 20°C.

F 171.—Similar to F 139.

F 172.—Similar to F 139 but chlamydospores terminal and rare.

F 173.—Similar to F 139.

F 174.—Typical *F. udum* except in lacking chlamydospores and producing some dark mineral red pigment on rice at 30°C.

F 175.—Similar to F 174.

F 176.—Typical *F. udum* except in producing some dark mineral red pigment on rice at 30°C.

F 13.—In colour production and chlamydospores true to *F. udum*, but producing only microspores and no pionnotes.

F 15.—Typical *F. udum* except in producing Indian red and cinnamon rufous colours on rice at 30°C.

Fungi causing sunn-hemp wilt

F 18.—In this culture the hooked spores are exceptional and they are not produced in a pionnotal slime, but in other respects the culture is true to *F. udum*.

F 19.—The apices of the spores are rounded or bluntly pointed. No colours are formed on rice at 20°C. and at 30°C. the dark vinaceous colour of *F. vasinfectum* occurs. There are no chlamydospores. Microconidia are produced in false heads on P. D. A. at 30°C.

F 26.—The colours and chlamydospores are typical of *F. udum*. No long spores are produced and pionnotes are absent.

F 166.—The colours are fairly typical of *F. udum* at 30°C., but with the addition of some pale vinaceous pink. Colour is lacking at 20°C. Chlamydospores are also typical. No long spores are produced and the pionnotal slime of microspores is pale instead of bright coloured.

F 168.—The colours are typical of *F. udum* at 30°C. but lacking at 20°C. Chlamydospores are correct for *F. udum*. Long spores are lacking but microspores are produced in typical pionnotal slime.

Fungi causing a low percentage of wilt

PIGEON-PEA

F 3.—Only three plants were wilted by this organism. The colours produced are nearer those of *F. vasinfectum* than *F. udum*. The sharply pointed spores and the well-developed foot-cell are not like *F. udum*.

F 4.—The colours are not typical of *F. udum* but as long spores are lacking and even microspores are rare, and the fungus was not grown at 20°C., a decision on identity of the fungus cannot now be reached.

SUNN-HEMP

F 167.—In colour and spore shape this culture much more closely resembles *F. vasinfectum* than *F. udum*. Microconidia are produced in false heads on P. D. A. at 30°C.

F 169.—The spores are bluntly pointed. The bright yellow and orange colours of *F. udum* are lacking. The anthracene purple and dark vinaceous brown colours and the reaction to potassium hydroxide and hydrochloric acid are those of the purple-pigmented isolates of *F. udum* rather than the purples typical of *F. vasinfectum*, which become distinctly red with hydrochloric acid. Microconidia are produced in false heads on P. D. A. at 30°C.

F 170.—The culture produces no spores and the colours are typical of neither *F. vasinfectum* nor *F. udum*.

Cultures F 25 and F 147, causing cotton wilt, may be regarded as *F. vasinfectum* or one of its varieties or forms. All the cultures causing high percentage of pigeon-pea wilt are *F. udum* provided the form circle is enlarged sufficiently to include those forms producing anthracene purple or similar pigments, which change to dull violet black with potassium hydroxide, certain forms producing no chlamydospores, and forms producing few or no long-septate spores (certain of these produced them in a later experiment).

This is a species with wide variation. If all these isolates are not to be regarded as *F. udum*, and instead specific rank is given to such characters as presence or absence of the anthracene purple pigment, presence or absence of terminal and intercallary chlamydospores, relative proportions of short and long spores, presence or absence of a pionnotal slime, of sclerotia and so on, there will be almost as many species as there are isolates.

It seems reasonable to regard also as *F. udum*, the cultures F 18, F 26, F 166 and F 168 which cause wilt of sunn-hemp, and a list of some of the more variable characters of this species, evident in the isolates here studied, is as follows :

Colours on steamed rice

Barium yellow, picric yellow, naphthalene yellow, citron yellow, amber yellow, antimony yellow, mustard yellow, Naples yellow, pinard yellow, honey yellow, cream buff, apricot buff, pale ochraceous buff, warm buff, apricot orange, mars orange, light seal brown, chestnut brown, cinnamon rufous, hazel, coral pink, corinthian pink, sea-shell pink, pale vinaceous pink, vinaceous, carnelian red, Indian red, dark mineral red, mars violet, Indian purple, anthracene purple, naphthalene violet, dull purplish black. Some cultures may lack colour entirely. The most striking colours are the bright yellows and oranges.

Pionnotes

Pionnotes may be absent, discrete or covering the surface of the medium as a thick slime, with the following colours :

Ivory yellow, light vinaceous cinnamon, vinaceous cinnamon, pale pinkish cinnamon, salmon buff, ochraceous buff, tilluel buff, hydrangea pink, vinaceous pink.

Conidia

Conidia may vary from entirely 0-septate spores in some cultures to 0-6 septate in others. The longer spores are usually hooked at the end, the shorter ones are curved and sometimes bent almost at right angles in the middle.

Chlamydospores

Chlamydospores may be absent, few or abundant, but when present are both terminal and intercallary, and may be in chains or in groups.

Sclerotia

Sclerotia large and fleshy, either pale or dark in colour.

The isolates F 3, F 4 and F 170 have been insufficiently studied. Cultures F 19, F 167 and F 169, which cause a certain amount of sunn-hemp wilt, are quite different from both *F. udum* and *F. vasinfectum*. The bright yellow and orange colours of *F. udum* are lacking, the spores are never hooked, and are thick (the mean width of 50 spores of F 169 was nearly 40 per cent greater than the width of the widest spores of *F. udum* and *F. vasinfectum*, of which some hundreds were measured).

The author was impressed by the likeness of many of the cultures which can best be regarded as typical *F. udum* to the fungus *Fusarium lateritium*

var. *uncinatum* Wr. as described by Wollenweber [1938]. According to him these fungi differ in the following characters :

F. udum	*F. lateritium* var. *uncinatum*
Spores sickle-shaped	Spores hooked
Produces ' orange-bis ' conidia.	Produces salmon-coloured conidia
Produces orange colour on steamed rice	Produces orange and yellow on steamed rice
Produces terminal chlamydospores	Produces no terminal chlamydospores
Belongs to section *Elegans*	Belongs to section *Lateritium*

A glance at Butler's original drawings will show at once that, although many of his spores are sickle-shaped, several are distinctly hooked. It is the shorter spores that are sickle-shaped, the longer ones hooked, and some of the cultures studied by the author have been found to produce both kinds.

Butler described the pionnotal stage as ' salmon-pink ' only occasionally, on rice, orange-red. They are thus like those of *F. lateritium* var. *uncinatum*. It will be seen that the cultures examined varied considerably on rice. But a vital distinction should be in the chlamydospores. All the cultures described here either produced both terminal and intercallary chlamydospores or produced none at all. It is characteristic of the section *Lateritium* that its members produce no terminal chlamydospores. Wollenweber [1938], however, stated of *F. lateritium* var. *uncinatum* that ' The chlamydospores form, in contrast to *Elegans*-Fusaria, *if one disregards occasional exceptions** not terminally, but intercallary, more seldom single than in chains, and sometimes in clusters '.

Relationship between *F. vasinfectum* Atk., *F. udum* Butl., *F. lateritium* Nees var. *uncinatum* Wr. and the doubtful forms

A culture of *F. lateritium* Nees var. *uncinatum* Wr. was secured from the Centraalbureau voor Schimmelcultures, Baarn. It was considered necessary to include in the comparison typical cultures of *Fusarium vasinfectum* and its varieties and forms. These also were obtained from the Centraalbureau.

The final test of the validity of *F. udum* as a species would be to obtain an isolate of the fungus from Butler's original material in the Herbarium Crypt. Ind. Orient. His original collection from Dehra Dun and in addition some plants artificially inoculated by him were available, and attempts were made to isolate the fungus. They were unsuccessful and the fungus is probably dead. There is no culture of *F. udum* which has descended from Butler's type culture. The herbarium specimens are unsuitable for comparison. We are obliged to rely on his written description.

F. udum, as stated above, seemed to differ from *F. lateritium* var. *uncinatum* only in regard to chlamydospores, the latter fungus belonging to a group not producing terminal chlamydospores. It was therefore a matter of surprise when, on examining the type culture received from Baarn, it was found to have a considerable number of terminal as well as intercalary chlamydospores.

Table II summarises the major differences in cultural characters of a selection of the more variable forms of *F. udum*, *F. lateritium* var. *uncinatum*

*The italics are the author's.

TABLE II

Morphological and cultural characters of Fusarium vasinfectum *Atk.*, F. udum *Butl. and* F. lateritium *Nees var.* uncinatum *Wr., grown for 21 to 23 days at 20°C.*

Culture	Species	Septation of spores on 2 per cent P. D. A.	Shape of spores	Colours on rice	Media with chlamydospores
F 21	*F. vasinfectum* Atk. (from C. B. S.)	0—3	Ovoid to spindle, not foot-celled	Rocellin purple and neutral red	None
F 186	*F. vasinfectum* Atk. f. 1 Wr.	0—3	Ovoid to spindle or slightly curved, not-foot-celled	Rhodonite pink	P. D. A. (T. and I. abundant)
F 190	*F. vasinfectum* Atk. f. 2. Wr. et Rkg. (from C. B. S.)	0	Ovoid to spindle	Do.	P. D. A. (T. and I. moderate)
F 187	*F. vasinfectum* Atk. v. *zonatum* (Sherb.) Wr. (from C. B. S.)	0—2	Ovoid to spindle or slightly curved, not foot-celled	Dull violet black and neutral red	P. D. A. (T. and I. few)
F 188	*F. vasinfectum* Atk. v. *zonatum* (Sherb.) f. 1. (Lk. et Bail.) Wr. (from C. B. S.)	0	Ovoid to spindle	None	P. D. A. (T. and I. moderate) Rice (T. and I. moderate)
F 189	*F. vasinfectum* Atk. v. *zonatum* (Sherb.) f. 2 (Lk. et Bail.) Wr. (from C. B. S.)	0—3	Ovoid to spindle or slightly curved, not foot-celled	Neutral red	P. D. A. (T. and I. moderate) Rice (T. and I. few)

TABLE II—*contd.*

Culture	Species	Septation of spores on 2 per cent P. D. A.	Shape of spores	Colours on rice	Media with chlamydospores
F 191	*F. vasinfectum* Atk. v. *lutulatum* (Sherb.) Wr. (from C. B. S.)	0—2	Ovoid to spindle or slightly curved, not foot-celled	Rhodonite pink	P. D. A. (T. and I. few)
F 25	*F. vasinfectum* Atk. (from cotton, Bombay)	0—3	Ovoid to spindle, not foot-celled	Neutral red	P. D. A. (T. few)
F 169	Section Martiella ?	3	Slightly curved, with rounded ends, not foot-celled	Dark livid brown	P. D. A. (T. and I. moderate) Rice (T. and I. abundant)
F 19	Do.	0—3	Ovoid to spindle or slightly curved, not foot-celled	Ageratum violet	None
F 26	*F. udum* Butl. (Sunn-hemp)	0	Ovoid to spindle	Barium yellow and apricot orange	P. D. A. (T. and I. few)
F 166	*F. udum* Butl. (Sunn-hemp)	0—6	Ovoid to spindle or sickle or slightly curved, strongly hooked, not foot-celled	Amber yellow and apricot orange	Rice (T. and I. moderate)
F 2	*F. udum* Butl. (Pigeon-pea)	0—3	Ovoid to spindle or sickle or slightly curved, hooked, not foot-celled	Citron yellow and apricot orange	None

F 6	Do.	0—several	Ovoid to pindle or sickle or slightly curved, strongly hooked, not foot-celled	Citron yellow and traces of salmon buff	Hyphal swellings only on P. D. A.
F 10	Do.	0—several	Do.	Do.	None
F 59	Do.	0—3	Ovoid to spindle or sickle or slightly curved, strongly hooked, occasionally slightly foot-celled	Barium yellow, apricot orange and dark livid brown	Do.
F 174	Do.	0—several	Ovoid to spindle or sickle or slightly curved, hooked, not foot-celled	Barium yellow and apricot orange	P. D. A. (T. and I. few) Rice (T. rare)
F 185	*F. lateritium* Nees v. *uncinatum* Wr. (from C. B. S.)	0—4	Ovoid to spindle or sickle or slightly curved, hooked, not foot-celled	Barium yellow, apricot orange and Hay's russet	P. D. A. (T. and I. abundant) Rice (T. and I. abundant)

and *F. vasinfectum* with its varieties and forms, when grown on potato dextrose agar and steamed rice at 20°C. Plates XXXIX and XL give an idea of the range of colours produced on steamed rice by the three species. Camera lucida drawings of typical conidia are figured in Plate XLI, which also shows the development of terminal and intercallary chlamydospores of *F. lateritium* var. *uncinatum*.

Discussion

Butler [1926] decided that *Fusarium udum*, which he had described earlier [Butler, 1910] as the cause of wilt of pigeon-pea, is a synonym of *Fusarium vas infectum*. His description [Butler, 1910] of *Fusarium udum* was as follows:

'Mycelium parasitic within the roots of the host plant or saprophytic and then creeping, hyphae hyaline, slender, much branched, usually with little aerial growth; microconidia of the *Cephalosporium* type, produced successively on the ends of short simple or clustered conidiophores and remaining bound in a drop of liquid after abjunction, unicellular or with one or more septa, elliptical or falcate, hyaline singly, salmon pink in mass, occasionally developing from the surface of minute spherical stromata and then of the *Tuberculatia* type, 5-15 × to 2-4μ in diameter; microconidial stage in culture usually moist and bacteria-like, white to salmon-pink, occasionally (on rice) orange red, never green or purple; macroconidia of the *Fusarium* type, formed as the microconidia but on shorter conidiophores and becoming free as soon as abjuncted, falcate 3- to 5-septate, hyaline, 15-50 × 3-5μ in diameter, usually late in appearing; chlamydospores, round or oval, rather thick-walled, hyaline, sometimes in short chains, 5 to 10μ in diameter.

Parasitic in roots of *Cajanus indicus* and saprophytic in soil, India.'

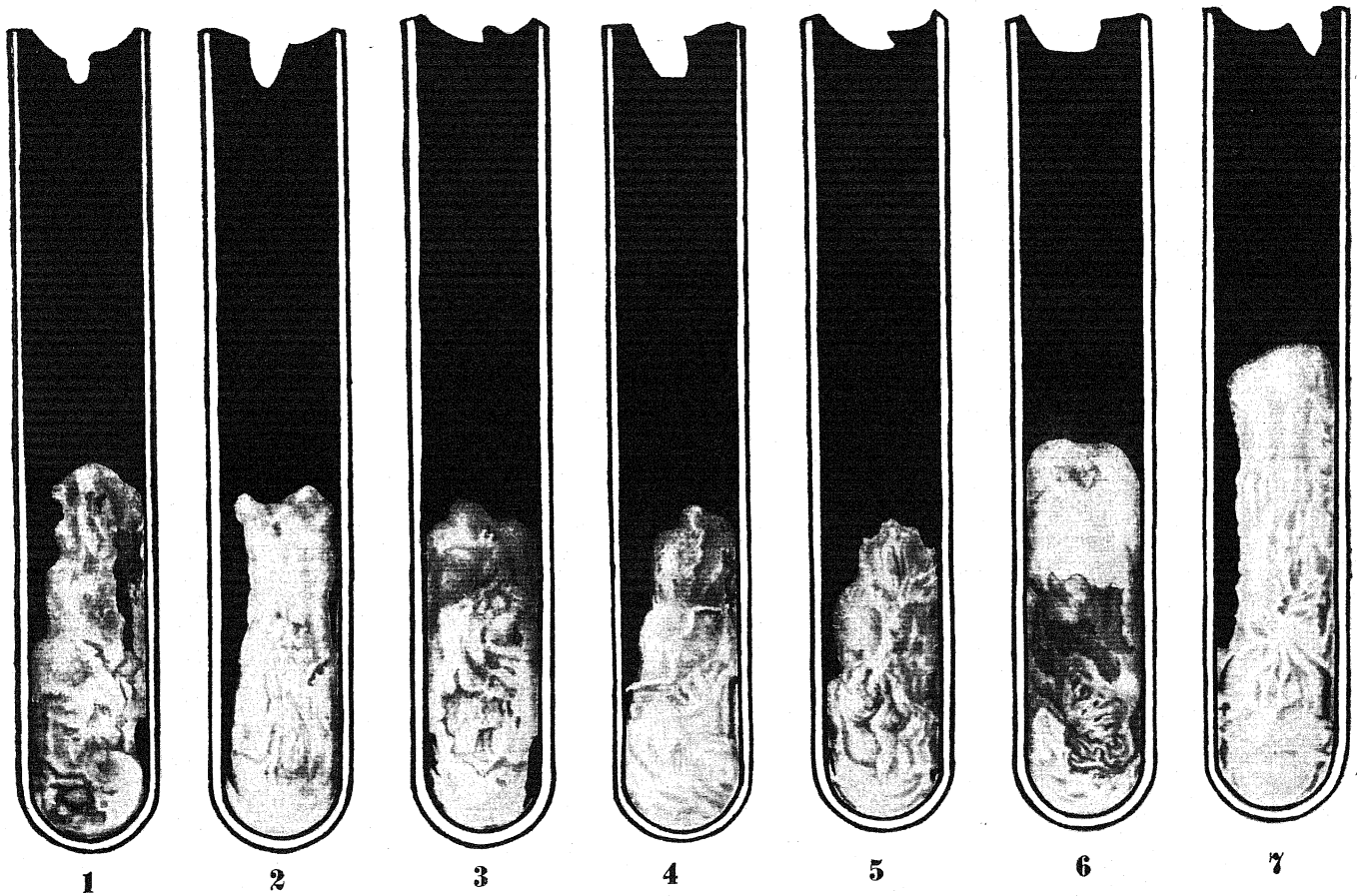
Butler's argument [1926] for regarding *F. udum* as a synonym of *F. vasinfectum* was of a rather indirect nature. The work described was done with cotton and *Sesamum* wilt fungi, not with the pigeon-pea organism, so that the comparison was between the *Sesamum* fungus and *F. vasinfectum* of cotton, and the conclusion as far as it relates to *F. udum* appears to be indirect and to rest on the statement: 'Furthermore, I have vainly endeavoured to find a true distinguishing character between the *Sesamum* fungus and *F. udum*, described by me in 1910 as the cause of the pigeon-pea wilt in India.'

The argument runs as follows:

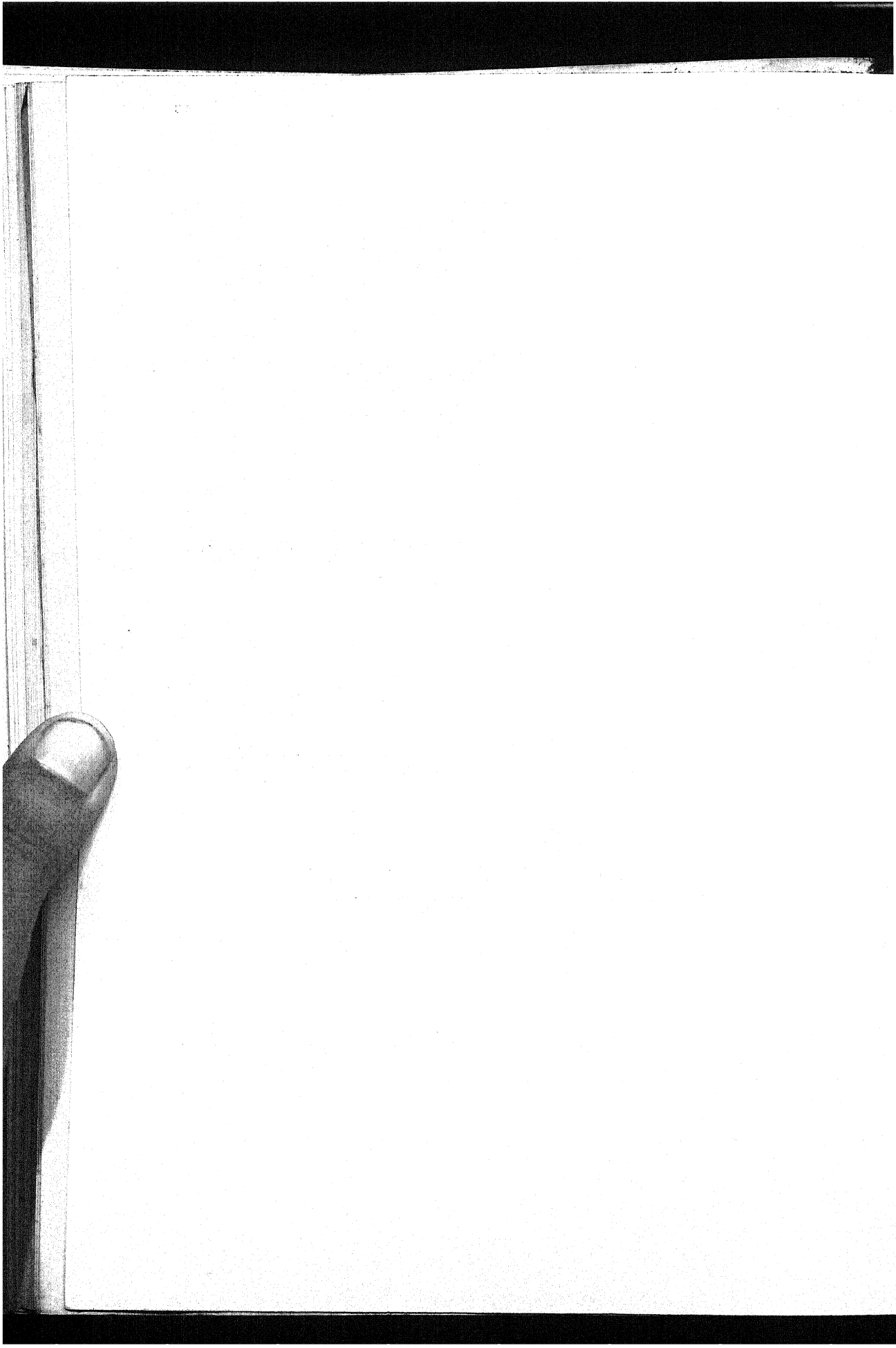
'Small has recently studied in great detail what he considers to be *F. udum*, which he found to be attacking a number of different plants in Uganda [*Kew Bull.*, 1920, p. 321; 1922, p. 269; 1925, p. 118]. Hence, though in India the strain of *F. udum* parasitic on pigeon-pea seems to be restricted to that host, in Uganda the morphologically and culturally similar fungus is capable of attacking not only pigeon-pea but a considerable number of other plants, and this strengthens the possibility that the sesamum parasite may be merely another strain of the same species.

Fusarium udum itself was named without prejudice to the question whether it had not been previously included amongst the named members of the genus. The chief diagnostic characters were the pionnotal type of sporulation, the flesh to salmon-pink colour on many media with absence of blue colours, and the tubercular stromata on potato and plantain. Subsequent isolations at Pusa, however, showed that the first of these characters was not constant, some strains giving a copious aerial mycelium on agar slants. Nodular sclerotia also are now known to be commonly produced by many members of the genus and occur in both *Fusarium cubense* and the sesamum parasite in which they are blue on potato but gradually turn pink if placed in lactic acid. Bessy's conclusions that the red and blue colours are only chemical modifications of the same pigment has been substantiated by subsequent investigators, and there seems every probability that the blue or violet colours developed in *F. cubense* and the sesamum fungus could also be produced by *F. udum* on suitable media. Small indeed [*Kew Bull.*, 1922, p. 282] obtained a pale blue pigment in his strain in two cultures.

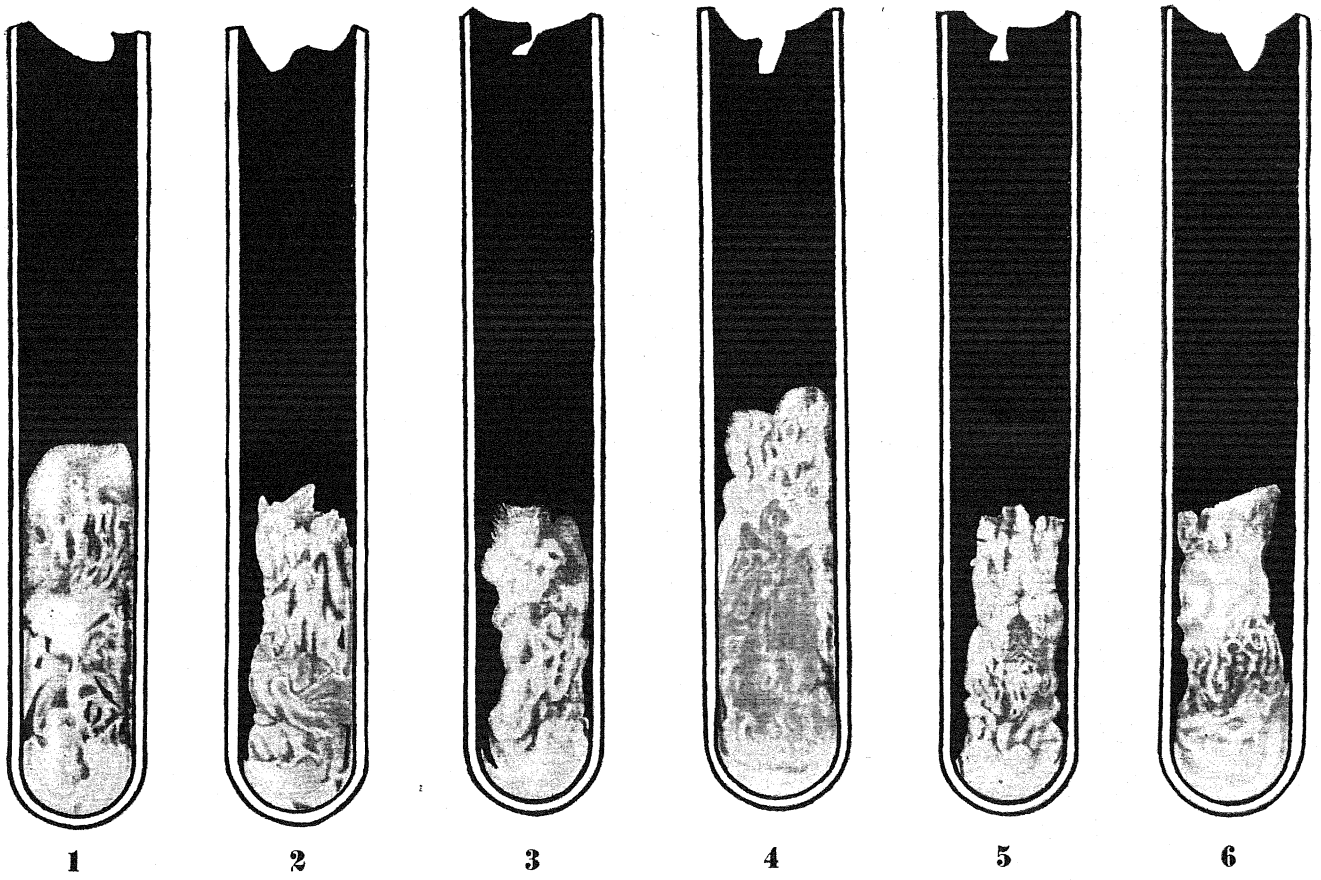
CULTURES OF *FUSARIUM VASINFECTUM* GROWN ON STEAMED RICE
(20 TO 29 DAYS AT 30° C.)



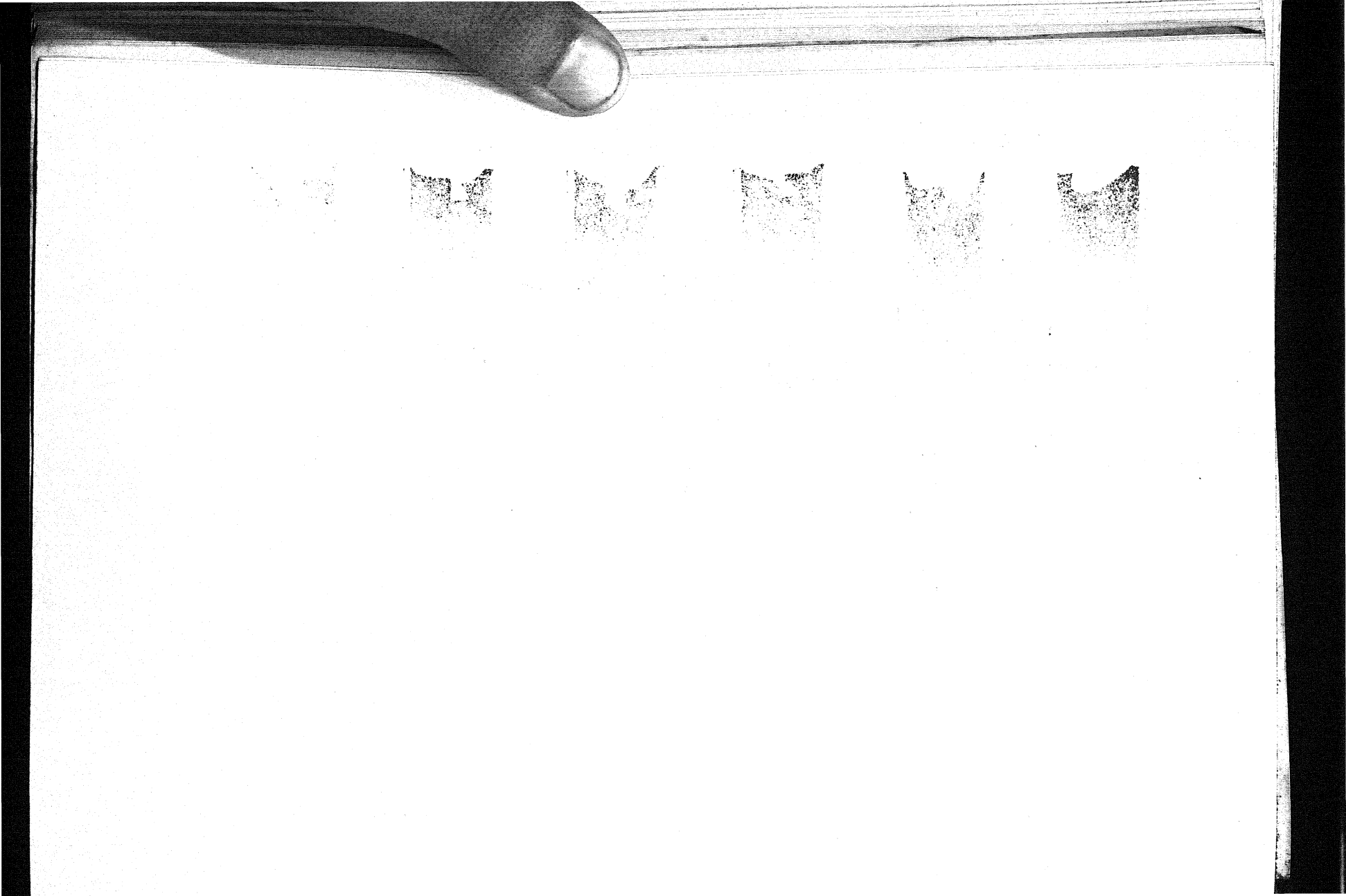
1. F 21—*F. vasinfectum* Atk. 2. F 186—*F. vasinfectum* Atk. *f.1* Wr. 3. F 190—*F. vasinfectum* Atk. *f.2* Wr. et Rkg. 4. F 187—*F. vasinfectum* Atk. var. *zonatum* (Sherb.) Wr. 5. F 188—*F. vasinfectum* Atk. var. *zonatum* (Sherb.) *f.1* (Lk. et Bail.) Wr. 6. F 189—*F. vasinfectum* Atk. var. *zonatum* (Sherb.) *f.2* (Lk. et Bail) Wr. 7. F 191—*F. vasinfectum* Atk. var. *lutulatum* (Sherb.) Wr.



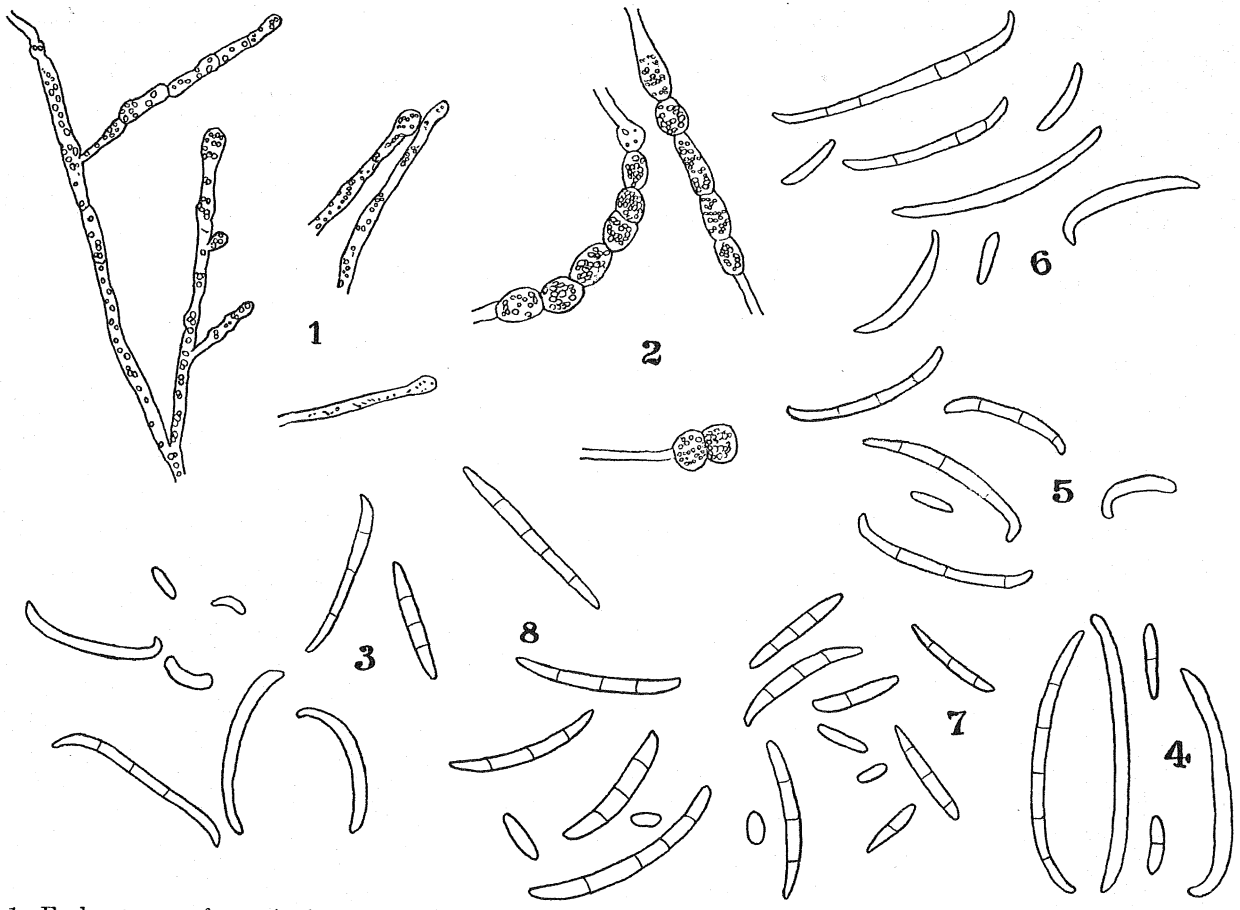
CULTURES OF *FUSARIUM* PATHOGENIC ON PIGEON-PEA AND SUNN-HEMP, GROWN ON STEAMED RICE (22 TO 31 DAYS AT 30° C)



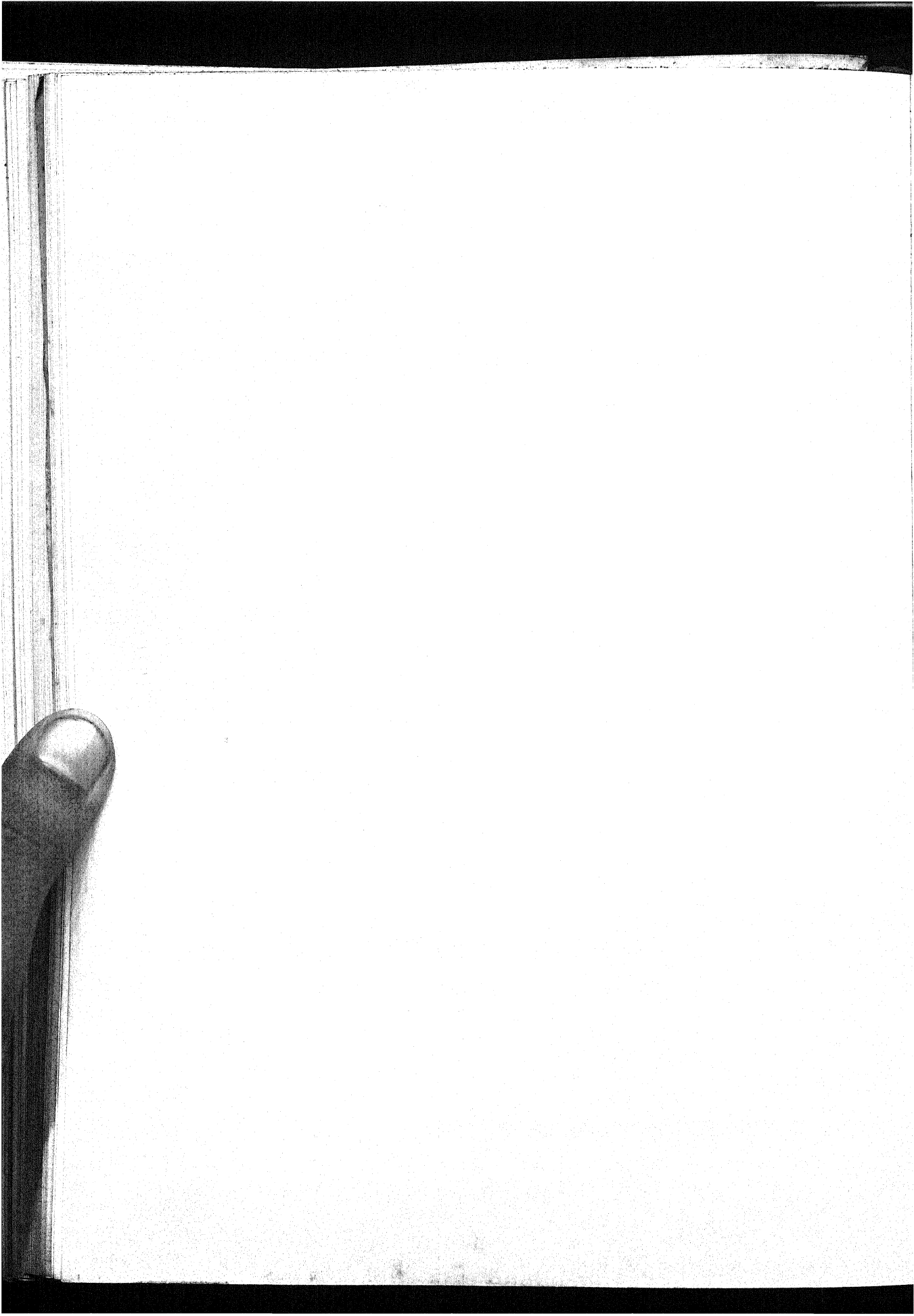
1. F 169—A weak parasite of sunn-hemp (Section Martiella ?); 2. F 26—*F. udum* Butl. var. *crotalariae* n. v.; 3. F 166—*F. udum* Butl. var. *crotalariae* n. v.; 4. F 2—*F. udum* Butl. var. *cajani*; n. v. 5. F 10—*F. udum* Butl. var. *cajani* n. v.; 6. F 185—*F. lateritium* Nees var. *uncinatum* Wr. (*F. udum* Butl.)



CONIDIA AND CHLAMYDOSPORES OF *FUSARIUM UDUM* AND *F. VASINFECTUM* GROWN ON POTATO DEXTROSE AGAR (21 TO 23 DAYS AT 20°C) (×640)



1. Early stages of terminal and intercallary chlamydospore formation by F 185—*F. lateritium* Nees. var. *uncinatum* Wr. (*F. udum* Butl.) 2. Late stages of the same. 3. Pionnotal spores of the same. 4. Pionnotal spores of F 166—*F. udum* Butl. var. *crotalariae* n. v. 5. Pionnotal spores of F 59—*F. udum* Butl. var. *cajani* n. v. 6. Pionnotal spores of F 174—*F. udum* Butl. var. *cajani* n. v. 7. Spores from agar surface, F 21—*F. vasinfectum* Atk. 8. Spores from agar surface, F 186—*F. vasinfectum* Atk. f.l Wr.



Recently, Hansford, confronted with the difficulty of distinguishing *F. cubense* in culture from many other strains of the Elegans section of the genus, has concluded that the present classification of the section is useless and that the conception of a species of *Fusarium* must be broadened [*Proc. 9th West Indian Agric. Conf.*, 1924, pp. 43-44, 1925]. He considers that it is preferable to regard all the Elegans forms which he has encountered as strains of a single species. With this view, my own observations are in harmony and I now regard *F. udum* and the two forms discussed in the present paper as strains of the same species. Furthermore, *F. cubense* is so similar to the sesamum fungus that it can scarcely be considered as a distinct species, either on morphological or cultural characters. It appears to possess strains differing in their selective parasitism, *Musa cavendishii* being immune from it in the West Indies but susceptible in the Canaries. Finally, through *F. cubense*, which both Brandes and Wollenweber have noted to be scarcely different from *F. vasinfectum*, one is led to include the latter in the group of closely allied strains. In so doing I have reversed my previous opinion [*Rept. Agric. Res. Inst. and College, Pusa*, 1913-14, p. 54, 1914] which was based on cultural differences between the American and Indian cotton wilt fungi, these differences being now regarded as being too inconsistant to be used as satisfactory criteria.

Thus the wilt-producing fungi attacking cotton, sesamum and pigeon-pea in India may, in the writer's opinion, best be considered to be strains of *F. vasinfectum* Atk., which itself may be merely a strain of one of the earlier described species of the genus.

It appears as if Wollenweber has never been quite able to accept the view that *Fusarium udum* is synonymous with *F. vasinfectum*. In his most recent paper on the subject [Wollenweber, 1938] he has given a number of characters by which *Fusarium udum* may be distinguished from *Fusarium vasinfectum* Atk. and has listed also the distinguishing characters of *F. lateritium* var. *uncinatum* Wr., another species which is considered to cause a rather different disease. The researches described by the author have shown that both *F. lateritium* var. *uncinatum* and Butler's *F. udum* have hooked spores, both produce, in some isolates at least, salmon-coloured pionnotes, and on rice some isolates of both produce a yellow as well as an orange pigment. Formation of chlamydospores is a highly variable character, but *F. lateritium* var. *uncinatum*, as well as *F. udum*, can form both terminal and intercallary ones (Plate XLI). It is noteworthy that *F. lateritium* var. *uncinatum* is placed in the key by Wollenweber and Reinking [1935] in the group with microconidia normally present, whereas *F. lateritium* Nees belongs to the group with small conidia normally absent or one- to more-celled. This characteristic coupled with the type of chlamydospores produced places *F. lateritium* var. *uncinatum* in the section *Elegans*. Yet the hooked spores and the pigmentation admittedly resemble more closely those of the section *Lateritium*. Thus while the evidence appears overwhelming that *F. lateritium* var. *uncinatum* Wr. is a synonym of *F. udum* Butler, it is not a simple matter to decide whether or not the fungus should be regarded as a true member of the section *Elegans* or whether the dividing line between these two sections is made indistinguishable by this more or less intermediate form.

We may at this point consider the suggestion of Wollenweber [1913] that Butler's *Fusarium udum* is invalid and the proposal of the name *F. Butleri* for this species. As a footnote he wrote ' I propose the name *F. Butleri* for this species, because the name *F. udum* has already been used by Berkeley [1841] and refers to a distinct old species, well-known by its pionnotes stage covering the cut surface of oak, elm and other trees. It is also found on Irish potatoes, tulip bulbs and in the soil. It was temporarily transferred by

Saccardo [1886] to the genus *Pionnotes*, which, however, has no sound morphological basis [Appel and Wollenweber, Grundlagen.....1910].' Berkeley's fungus was named *Fusisporium udum*, not *Fusarium udum*. In 1886 this was changed by Saccardo to *Pionnotes uda* (Berk.) Sacc. Pionnotes was combined with *Fusarium* by Appel and Wollenweber only in 1910, after Butler had named *Fusarium udum*, though in the same year. Thus *Fusarium udum* (Berk.) Wr. is a non-valid homonym and on that account *Fusarium udum* Butl. cannot be rejected in favour of *F. Butleri*.

Next, is *F. udum* to be regarded as a distinct species, or is it to be merged with *F. vasinfectum* ? It is seen that the highly pathogenic isolates are rather distantly removed from *F. vasinfectum*. The only reason for merging *F. udum* and *F. vasinfectum* would be that a complete range of intermediate forms existed. Although the cultures vary considerably, there is no evidence at present to suggest that such a complete range could be demonstrated. A thorough comparison has been made of typical variants of *F. udum*, with all varieties and forms of *F. vasinfectum*. In colour and spore form they comprise a group which, though variable, does not appear at its extreme limits to overlap *F. udum*, either as regards the hooked conidia or the pigments produced. For the time being, at any rate, the two species should be regarded as distinct.

The significance of these conclusions may be considered in relation to the pathological aspect. Butler in 1910 described *F. udum* in its narrower sense, and as late as 1918 he held the view that this fungus was restricted to pigeon-pea as a host. In 1926 he merged the species with *F. vasinfectum*. He may not have realised it at the time, but he was to a large extent widening the conception of *F. vasinfectum*, not only to include a different species, but perhaps to include a species which might even not belong to the section *Elegans* at all. Possibly other workers at the same time also had a wide conception of the species *F. udum*. Particularly is this true of the work of Small. In 1925 Small crystallised his ideas on this fungus, and decided that its pathogenicity depends less on the strain of the fungus and the presence of a possible host plant than on the environmental conditions under which the fungus comes into contact with its host. With regard to the cultural characters of the fungus he says ' emphasis may be laid on the constant nature and dirty- or creamy-yellow colour of the pionnotes.' Finally, of its taxonomic position he concludes ' The *F. udum* of these notes is also distinct from *F. udum* (Berk.) Wr. and from Sherbakoff's variety *solani* of the species, and while it resembles *F. striatum* in many points, particularly in the typical presence of pseudo-pionnotes, it remains nearer to *F. radicicola*.' *F. radicicola* is now regarded by Wollenweber and Reinking [1935] as a variety of *F. javanicum*, which is a member of the section *Martiella*, having spores with much thicker and more durable cell walls and septations than those of the members of the section *Elegans*. The colours of the fungus and of its spore-masses, judged by the rather meagre description given by Small, do not resemble the colours typical of *F. udum*. *F. javanicum* var. *radicicola* is a cause of potato tuber-rotting in America, and Small found his fungus to be so in Uganda. Experiments conducted at the Imperial Agricultural Research Institute have failed to demonstrate that *F. udum* can cause rotting

of tubers. On the whole, it seems probable that Small was working with a fungus or fungi distinct from Butler's *F. udum* and more closely related to culture F 169 of this work, which may be a member of the section Martiella.

At present it is not clear whether Wollenweber's isolate of *F. udum* differs from those obtained by the author in respect of its pathogenicity. Wollenweber describes the fungus as a foot-rot organism. The author's isolates produce a true wilt, but in the plants which are killed in the seedling stage a considerable amount of rotting of the cortex also occurs. It may be noted that the first occurrence of 'wilt' in Wollenweber's experiments was when the plants were nine weeks old. This is certainly not typical of a foot-rot disease as understood in the *Fusarium* foot-rots of other crops, which usually show the symptoms in the very young stages. Butler [1910], describing his culture solution experiments, found that in the roots above the level of the solution the fungus 'led to browning of the cortical cells, visible externally as a distinct brown mark at the point of inoculation'. His figure (Plate II, fig. 1) certainly suggests that although the fungus is primarily a vascular invader it is capable also of rotting the roots. The point can only be settled by inoculation experiments.

It is proposed to call the wilt organism of *Cajanus cajan* '*Fusarium udum* Butl. var. *cajani*' and that of *Crotalaria juncea* '*Fusarium udum* Butl. var. *crotalariae*.'

Summary

(1) This paper deals with the identity of a number of isolates of *Fusarium*. capable of causing wilt of cotton (*Gossypium* sp.), pigeon-pea (*Cajanus cajan*) and sunn-hemp (*Crotalaria juncea*).

(2) The fungi were grown on 2 per cent potato dextrose agar, Brown's agar, Brown's starch agar and steamed rice, and compared for all important cultural characteristics.

(3) The cultures which cause typical wilt of high percentages of pigeon-pea and sunn-hemp were found to differ from *Fusarium vasinfectum* Atk. in three major characteristics, namely, that they produced abundant spores in pionnotes, these spores usually tended to be strongly hooked at the apex, and bright orange and yellow colours were produced on steamed rice, whereas *F. vasinfectum* produced few or no pionnotes, the spores although curved were not hooked, and the predominant colour on steamed rice was a red hue which changed to deep purple on addition of 2 per cent potassium hydroxide solution.

(4) Several cultures causing wilt of sunn-hemp produced spores much broader than those of *F. vasinfectum* or the typical pigeon-pea and sunn-hemp organisms, and they probably belong to the section Martiella.

(5) The typical pigeon-pea and sunn-hemp wilt organisms, although sharply differentiated on a parasitic basis, are indistinguishable from one another morphologically and culturally, and are in fact *Fusarium udum* Butl., a highly variable species particularly with regard to ability to form chlamydospores, and as regards length of spores and range of colours produced.

(6) A number of isolates of *F. udum* were compared with *F. lateritium* var. *uncinatum* Wr. and also with cultures of all varieties and physiologic

forms of *F. vasinfectum*, obtained from the Centraalbureau voor Schimmelcultures, Baarn. This experiment strikingly confirmed the previous conclusion that *F. udum* is a separate species from *F. vasinfectum*. It proved that *F. lateritium* var. *uncinatum* is a synonym of the earlier species *F. udum*, and that it produces terminal as well as intercallary chlamydospores.

(7) The names *F. udum* Butl. var. *cajani* and *F. udum* Butl. var. *crotalariae* are proposed for the wilt organisms of *Cajanus cajan* and *Crotalaria juncea* respectively.

ACKNOWLEDGEMENTS

The author is deeply indebted to Mr Hari Har Prasad, Assistant to the Imperial Mycologist, who throughout this and previous work on *Fusarium* has given invaluable help in maintaining cultures and in numerous other ways.

The author also thanks Dr P. G. Krishna, Agricultural Chemist, H. E. H. the Nizam's Government, Mr P. R. Mehta, Assistant Professor of Botany, Agricultural College, Cawnpore, and Mr R. D. Bose, Superintendent, Botanical Substation, Imperial Agricultural Research Institute, Pusa, for supplying diseased material, and Dr. B. N. Uppal, Plant Pathologist to Government of Bombay, for supplying two cultures.

REFERENCES

Appel, O. A. and Wollenweber, H. W. (1910). *Arb. Biol. Reich.* **8**, 1-207
Atkinson, G. F. (1892). *Alabama Agric. Exp. Stat. Bull.* **41**
Brown, W. (1925). *Ann. Bot.* **39**, 373-408
Butler, E. J. (1910). *Mem. Dept. Agric. Ind.* (*Bot. Ser.*) **2**, No. 9
——— (1918). '*Fungi and disease in plants*': Thacker Spink and Co., Calcutta and Simla
——— (1926). *Agric. J. Ind.* **21**, 268-73
Padwick, G. W., Mitra, M. and Mehta, P. R. (1940). *Ind. J. Agric. Sci.* **10**, 707
Ridgway, R. (1912). '*Colour standards and colour nomenclature*': Washington
Saccardo, P. A. (1886). *Sylloge Fungorum* **4**, 726
Small, W. (1925). *Kew Bull.* 118-26
Wollenweber, H. W. (1913). *Phytopath.* **3**, 24-50
——— (1938). *Arb. Biol. Reich.* (*Berl.*) **22**, 339-47
Wollenweber H. W. and Reinking, O. A. (1935). '*Die Fusarien, ihre Beschreibung, Schadwirkung und Bekampfung.*' Berlin: Paul Parey
Wollenweber, H. W., Sherbakoff, C. D., Reinking, O. A., Johann, Helen and Bailey, Alice A. (1925). *J. Agric. Res.* **30**, 833-43

NOTE

After the Ms. was submitted for publication, I received a paper entitled 'The species concept in *Fusarium*' (Synder, W. C. and Hansen, H. N. 1940. *Amer. J. Bot.* **27**, 64-67). All of species *Fusarium* in the section *Elegans*, including *F. udum* Butl., are formally made physiologic forms of *F. oxysporum* Schl. The changes are based on 'the general nature of, and variability in, *Fusaria*', resulting from a study of a few of the species and varieties, and details of the evidence for the changes are not given. It has been clearly shown in the work described above that *F. udum* Butl. stands as a good species despite generalized remarks to the contrary. The significance and validity of the changes proposed, especially as they bear on the conclusions reached in Part III of this series of papers (*Ind. J. Agric. Sci.* **10**, 241-84 : 1940), will be the subject of further remarks.

INVESTIGATIONS ON *SPATHIUS CRITOLAUS* NIXON, AN IMPORTANT BRACONID PARASITE OF THE COTTON-STEM WEEVIL, *PEMPHERES AFFINIS* FST. OF SOUTH INDIA

BY

P. N. KRISHNA AYYAR

Parasitologist, Agricultural Research Institute, Coimbatore

(Received for publication on 19 July 1938)

(With Plates XLII and XLIII and two text-figures)

INTRODUCTION

SPATHIUS CRITOLAUS Nixon" is an indigenous primary ectophagous parasite on the grubs of the cotton-stem weevil, *Pempheres affinis*, in South India. It invariably attacks host-grubs in an advanced stage of growth. Normally the egg, larval and pupal stages of the parasite are all passed within the tunnel bored by the weevil-grub in the stem. The first record of this Braconid in association with this pest was by Ramakrishna Ayyar and Margabandhu [1936]. Beyond the mere record nothing was known regarding its biology, habits or host relations. A knowledge of these aspects is necessary not merely because of the possible utilization of the parasite in the control of the stem weevil but also because the biology of no member of the genus *Spathius* appears to have been studied in detail from South India. This study has been in progress for a period of over two years. The writer has been greatly assisted in this work, particularly in the routine part thereof, by Assistant Mr. P. S. Narayanaswami, and Fieldman Mr N. Muthuswami, the latter having been specially helpful in the collation of data and preparation of the tables.

THE HOST

Pempheres affinis has been known in India for over 25 years. It is by far the worst pest of cotton wherever it occurs in South India, causing a loss of about 30 per cent or more in the case of severe outbreaks. The injury inflicted is by the extensive tunnelling of the stem by the immature stages. This weevil under field conditions passes through nearly three successive generations during the cotton season, October to March, though considerable overlapping of generations occurs even at the beginning of the second brood. From a small population of a few immigrants to cotton fields in the initial stages of the crop, huge populations are built up as the season advances. The weevil appears to be an indigenous pest from all available evidence. Its original source appears to be from wild food plants of the genera, *Triumfetta*, *Sida* and *Hibiscus* scattered in hills and plains. Only five species of the genus *Pempheres* are known so far, all being confined to the Indo-Malayan region. In South India it has no effective natural enemy in the field.

Adult parasite (Plate XLII, figs. 1, 2, 3)

The parasite has been recently identified as a new species and described under the name *Spathius critolaus* [Nixon, 1939]. It is a slender, elongate, reddish-brown insect with a dark abdomen and vestigial wings, having a strong resemblance to *Cremastogaster* ants. The males are generally smaller and narrower than females. The length of ovipositor is often variable. Occasionally winged forms appear in both the sexes but winged males are rare and have been obtained only in one instance. Winged females are much commoner both in collections and rearings and make an appreciable proportion of the total females. The sizes of the adults vary within a wide range largely depending on the nutrition afforded during development by the host. The measurements of a large number collected from nature as well as those bred in the laboratory have been taken. The figures recorded do not include antennae and ovipositor.

Female.—Length ranges between 2·53 mm. and 3·25 mm. averaging 3·05 mm. Width at the widest part of the abdomen varies from 0·70 mm. to 0·85 mm. averaging 0·78 mm.

Male.—Length varies from 2·1 mm. to 3·12 mm. averaging 2·625 mm. Width varies from 0·67 to 0·75 mm. averaging 0·713 mm.

Technique

Being a larval parasite of a stem borer the study of the parasite is particularly arduous and difficult. *Pempheres* larvae are also perhaps the most difficult to rear under artificial conditions. Suitable stages of the pest were obtained by careful dissection of plants from the field and active non-parasitised healthy stages were selected for oviposition trials. Three to four grubs were introduced into small cells scooped out in a fresh cotton stem providing a thin door-like covering of the bark. The host-grubs were placed in position each inside a cell and covered by the lid of bark and the whole thing fastened by thin cotton threads. The stems were kept fresh and green by keeping them in culture solution provided in small tubes. The stem with the tube was placed in a cylindrical wire-gauze or glass cage with its open end protected by muslin covering. A pair of adult parasites was introduced into the cage and food in the shape of sugar or honey solution was supplied in a bit of sponge suspended from the stem. Later, raisins were substituted and were found to be more convenient. Every day these stems were removed and examined under a binocular for eggs and fresh stems with hosts supplied. For oviposition studies on a large scale, a pair of parasites or a mated female with a daily supply of fresh loaded stem and raisin were put inside long tubes (6 in. × 1 in.). After ovipositon the host with egg was either transferred into small paraffin cells made by sinking a heated nail head and covered with a cover glass or into small gelatin capsules. In order to gather accurate data on the percentage parasitism in nature, daily or weekly collections of plants were individually dissected and examined for noting the parasite stages.

Geographical distribution

A thorough study of its distribution has not been possible. The parasite has been observed and collected from Coimbatore and its environs, Erode

and surrounding villages, Ramnad and Malabar districts. From Malabar the parasite has been obtained from plant hosts other than cotton, such as *Triumfetta* and *Sida*. As a result of observations so far made, it may be assumed that the parasite is distributed throughout localities where the pest exists in any large numbers. It has also recently been recorded [Nixon, 1939] as being bred from seeds of *Prosopis spicigera* by S. D. Bhatt in the Punjab. In the latter place, the macropterous forms of males seem to be more predominant than macropterous females which is just the reverse of what occurs in South India.

Host range

The host preferences of the parasite seem to be somewhat restricted. In nature the parasite has been recovered from three distinct hosts, all being stem-borers, two of which are Curculionid grubs and the third a Bostrychid. It has been seen to parasitise *Pempheres* not only in cotton but also in various alternate host plants such as *Triumfetta rhomboidea*, *Sida acuta*, *Corchorus olitorius*, *Hibiscus esculentus*, *H. vitifolius*, *H. ficulneus*, and *Malvastrum coromandelianum*. Another insect which is found parasitised in nature, though infrequently, is the common weevil-borer grub of amaranthus (*Hypolixus truncatulus*). A third important alternate host is the Bostrychid borer (*Sinoxylon sudanicum* Lesne) infesting Cambodia cotton stalks. This Bostrychid attacks occasionally even green healthy plants in the field but prefers wilting plants in the field as also those collected and stored in the open. This phenomenon has been taken advantage of in the matter of mass-breeding of the parasite by manipulation of the host in large out-door cages.

Mating

Mating may occur immediately on emergence in a manner typical of most Braconids. The male appears to be particularly ready for copulation on issuing out of the cocoon even before feeding. In a small proportion of cases the sexes appeared to be indifferent to each other for a few minutes on coming out of the cocoon, especially when these were located at a distance in the same tube. The male apparently fails to recognise the female at a distance of nearly 5 or 6 in., but when they come near enough commence to show signs of excitement. Several copulating pairs have been watched in the cages and the duration of coupling has not exceeded 40 seconds but averaged about 20 to 25 seconds after which the female slips away. Very rarely have the males been noted to be able to effect a second copulation within a short interval. The same males however have been utilized to serve two to three females successfully at short intervals. Exposure to sunlight does not seem to make any difference in their behaviour except that they try to move away from the bright side.

Pre-oviposition period

The duration of time between emergence and egg-laying varied within a wide range in the species. This duration is probably governed by numerous factors such as mating, temperature and humidity, nature of food supplied

and also by the nature of the host provided. This period has been accurately recorded for about 63 individuals including 12 winged fertilized females and 10 virgin apterous females. In mated wingless females, the period ranges from 2 to 16 days averaging seven days for 41 cases. In mated winged forms, this period ranged from 2 to 28 days averaging 9·3 days for 12 cases. In the case of unmated females, the period ranged from 2 to 16 days averaging 10·2 days for ten virgins. In order to see the number and nature of the development of the egg, a few females were dissected under a binocular during the pre-oviposition period. On an average three to five developed eggs and as many partly developed ones were observed.

Oviposition

The preliminary search and manœuvres and the actual process of oviposition have been carefully watched in a number of cases in cages. Mating is not essential for oviposition. At first the female wanders over the stem or sides of cages or it may stop and rest quietly in any part of the cage without any sign of activity. Sometimes a spot is thoroughly inspected and the ovipositor inserted into and withdrawn from an artificial cleft as if feeling for the concealed grub. Often a spot apparently chosen was afterwards rejected. Not infrequently the female returns to the same spot after short wanderings and commences to evince a lively interest.

Process of oviposition.—After locating a spot containing an active host, it takes a firm stand, raises the abdomen and directs the tip of ovipositor forwards and commences a search with the tip. Perhaps the position of the host is discovered by touch through the agency of the ovipositor sheath. The antennae are either extended forwards or held diverged sideways. Very rarely they were directed downwards. The stylets of the ovipositor are slowly released and projected out with the two valves of the sheath yielding and forming a loop curving backwards. The stylets are slowly thrust deeper and deeper through the bark where it is weak, the loop formed all the while becoming wider and wider. Some times these are withdrawn fully or partially and two or three thrusts are quickly made in the same puncture. The stylets in a great majority of cases remained inserted for several minutes. The parasite has apparently stung the host and an egg is found laid soon after. After this operation, the ovipositor is withdrawn and sheathed and the parasite moves away from the spot. Sometimes all these operations were carried out resulting merely in the paralysation of the host, without the actual deposition of an egg. Very often artificial slits found in the stem are taken advantage of for insertion of ovipositor. The time taken for the process varied within a wide range. In the majority of cases the time taken varied between ten and 30 minutes. The maximum duration observed was about 90 minutes.

Time of oviposition.—Oviposition can take place probably during all hours of the day and night but more during night. Generally oviposition has been a common feature in cases where stems with host-grubs were supplied at 5 P. M. and removed at 9 A. M. the following day. On the other hand stems supplied at 9 A.M. and removed at 5 P.M. the same day did not give many egg-layings. Oviposition is more vigorous and regular in the earlier stage than in the later stage of the life of the female.

TABLE I

Oviposition record during 1936-37

Serial No.	Egg-laying period	Total eggs laid	Total longevity	Post-oviposition period
		Mated females (wingless)		
1	41	43	51	4
2	53	33	61	5
3	43	38	50	5
4	19	19	51	31
5	49	20	63	12
6	19	16	60	37
7	22	21	45	14
8	22	32	33	4
9	42	44	60	4
10	12	20	46	13
11	35	47	47	2
12	57	41	71	3
13	66	23	84	8
14	29	26	84	54
15	51	31	59	4
16	56	25	72	17
17	39	17	68	20
18	29	27	45	18
19	19	22	46	?
20	29	22	66	32
21	37	22	63	21
22	37	36	44	3
23	52	21	66	10
24	20	22	41	13
25	29	20	57	21
26	41	14	88	40
27	29	16	47	14
28	39	10	74	29
29	39	10	74	29
30	75	29	94	11
31	39	22	47	2
32	39	25	107	47
33	55	15	65	8
34	37	20	62	15
35	31	13	71	32
		Mated females (winged)		
1	15	11	39	38
2	56	53	64	7
3	16	13	34	8
4	25	24	62	33
5	13	8	51	25
6	71	22	109	23
7	24	16	57	5
8	30	25	48	6

TABLE I—*contd.*

Serial No.	Egg-laying period	Total eggs laid	Total longevity	Post-oviposition period
		Virgin females		
1	38	33	56	2
2	30	26	46	?
3	33	19	39	4
4	11	10	32	14
5	59	30	124	19
6	25	12	37	1
7	56	38	70	9
8	28	15	65	23

Method of locating the host.—A few experiments conducted in cages go to show that antennae are not probably very helpful in the process of oviposition. It is known that many species of parasites locate the host by search through the olfactory sense located in the antennae. A set of three experiments was conducted with mated ovipositing females after the complete removal of antennae leaving only minute stumps. Such females were not very steady in their gait and showed a slight change in their behaviour. One of these laid four eggs and the others six each subsequent to the removal of the antennae. The experiments are too few to be conclusive but it looks as if their efficiency is thereby considerably lessened and the egg-laying capacity diminished.

Position and number of eggs per host.—The number of eggs laid by a female per day was never large. It was commonly one, two or three and the maximum five. The eggs are laid indiscriminately on any part of the host. These may be placed crosswise or lengthwise without any attachment and these may be easily detached by slightest shock. Sometimes the eggs are found loosely lying in the host tunnel amidst excreta and frass. In the matter of laying only one egg per host it may be considered to be very economical and not wasteful because within its limited egg-laying capacity it can destroy a large number of hosts.

Egg-laying period and individual egg capacity.—In the case of mated wingless females the length of oviposition period ranged between 12 days and 66 days and averaged 38 days for 35 individuals (Table I). In the case of winged forms (also mated) the range was between 13 days and 71 days averaging 31·1 days for eight cases. Virgins showed a variation from 11 days to 59 days averaging 35 days for eight cases.

The same table furnishes records of the total number of eggs laid by a lot of 51 individuals. The maximum number noted for a female was 53 eggs. The egg-laying capacity for mated wingless forms varied from 13 to 47 eggs averaging 38 eggs for 35 cases. Mated winged forms showed a range from 8 to 53 eggs averaging 21·5 eggs for eight cases. Whereas virgins showed a range from 10 to 38 with an average of 23 eggs for eight cases, the virgins

evidently show a diminished egg-laying capacity. The post oviposition period is considerably prolonged in some cases and reaches a maximum of 54 days with a minimum of two days averaging 15·8 days for 49 individuals.

Selection of host stages.—The female always chooses an active host-grub and stings and paralyses it before oviposition. It seldom oviposits on grubs already paralysed by other insects or rendered inactive by other causes. It occasionally oviposits on host-grubs already paralysed by members of the same species. The females could not be induced to oviposit on other stages of *Pempheres*, *Sinoxylon* or *Hypolixus* such as prepupae, pupae, etc. Grubs boring deep into the centre of thick woody stems were rarely attacked being nearly inaccessible.

Effect upon the host and its survival.—The extent of paralysis of the host no doubt may vary according to circumstances. Usually the host-grub is rendered inert and dull. It becomes limp, relaxed and flaccid. It seldom moves though not dead. It does not feed and no peristaltic action is seen except when disturbed. In a few cases the heart beat, though feeble, was perceptible for some time. Such larvae showed one or more dark brown marks on the cuticle. These marks are really the scars produced by the sting or thrusts of the ovipositor. Some experiments have been conducted to test whether such grubs survive after freeing them of the eggs. These were never seen to revive, but continued, when kept in stems, to be fresh without decay or discoloration for a maximum period of about 15 days. They never survived but died a slow death after a period when they got dried up in the case of *Pempheres* and *Sinoxylon* grubs. It shows that such paralysis is eventually fatal in the case of these host-grubs. It is not a mere paralysis of the nerve centre since the sting marks have been found to be located on any part of the host-grub. The paralysis serves the admirable purpose of keeping the tissue of the host-grub fresh and in good condition for the newly hatched larva. The case of large-sized *Hypolixus* grubs is slightly different. In many cases the paralysis was only partial. Such larvae seemed to move and roll over slowly, wriggle or squirm to some extent apparently with a view to dislodge the egg or larvae. Even these grubs succumb soon after the egg hatches and the larva begins feeding.

Immature stages

Egg (*Plate XLIII, fig. 1*).—The eggs do not vary much in size generally but under-sized females have been seen to lay eggs of smaller size. The egg is barely visible to the naked eye. Maximum length 0·78 mm., minimum length 0·566 mm., average length 0·66 mm. Maximum width 0·15 mm., minimum width 0·10 mm., and average width 0·13 mm. for 35 eggs. The freshly laid egg is somewhat cigar-shaped and distinctly arched with the two poles unequal and rounded. The cephalic end is wider and more broadly rounded, being nearly one-and-a-half times as broad as the caudal end. Occasionally the shape departs a little from the normal in having a bulb-like expansion near the caudal end. This may be probably due to the uneven pressure at the time of deposition.

When freshly laid the egg is shining translucent white except at the caudal extremity which is glassy and transparent. The chorion is thin and smooth with no apparent sculpturing.

The time taken for hatching varies from one to two days averaging 1·4 days for 50 observed cases. It varies according to season and temperature within the range indicated.

Larva

I stage larva (*Plate XLIII, fig. 2*).—The newly hatched larva is a clear white delicate creature almost transparent. It is very nearly cylindrical with a slightly flattened head and 13 well-delineated body segments. The integument is apparently naked and unarmed without any spines, setæ or pigmentation but under the microscope presents a rough sculptured surface with setæ-like minute elevations. The head is slightly more chitinised than body segments though concolorous. Under a binocular a slightly dull pouch-like stomach is visible in the middle. The labrum is distinct and ventral and under a binocular the fleshy mouth-parts and sharp mandibles (Plate XLIII, fig. 3) are clearly seen. The tracheal apparatus is only imperfectly visible at this stage. The mandibles are somewhat triangular with a pointed sharp little tooth the lower curved border of which is provided with a pair of fine denticles.

Dimensions : Length varies between 0·62 mm. and 0·8 mm. averaging 0·68 mm. for 16 specimens measured. Width varies between 0·13 mm. and 0·175 mm. averaging 0·15 mm. Width of head varies from 0·1 mm. to 0·125 mm. averaging 0·11 mm.

On leaving the egg-shell, the larva crawls on the body of the host for a short distance and fixes its head on the host and commences to feed. Very often the eggs are found fallen off and detached in the tunnel and these hatch at a distance from the host. These tender larvæ crawl aimlessly by using the abdominal tip and mouth-parts for locomotion. The movement is comparatively rapid for its size. It attaches itself to the host if it comes across one in its journey. Otherwise it stops motionless, contracts and eventually dies. The larvæ do not linger much on the dorsal or exposed surface but generally crawl to lateral or ventral side of the host. In a few hours the larva gets swollen by feeding and the stomach contents show prominently with a yellowish tint.

II stage larva.—In general form it is similar to the previous stage but chiefly differs in colour and size. It is now less transparent. The shape is still cylindrical but the head is more globular. It is a little thicker in the middle and displays slight traces of the beginnings of urate cells. The cuticle possesses a fine covering of small setæ. The larva is widest between abdominal segments 1 and 3. Length varies from 1·05 mm. to 1·55 mm. averaging 1·21 mm. for 15 specimens. Width varies from 0·30 mm. to 0·35 mm. averaging 0·33 mm. Width of head varies from 0·15 mm. to 0·175 mm. averaging 0·33 mm.

III stage larva.—In this stage the larva is slightly arched becoming thicker in the middle with tapering extremities. Arched segmental convexities are visible and are larger in the first four abdominal segments which contract and dilate probably to help the larva in locomotions. The head is also comparatively larger and well differentiated. It is yellowish in colour. The white urate cells distributed on the sides and extending dorsally are more conspicuous and stand out distinctly. The trachæ are more ramified. The cuticular setæ

SPATHIUS CRITOLAUS NIXON

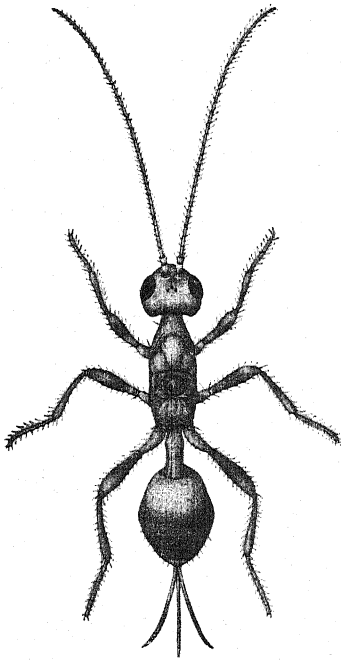


FIG. 1. Micropterous female (×13)

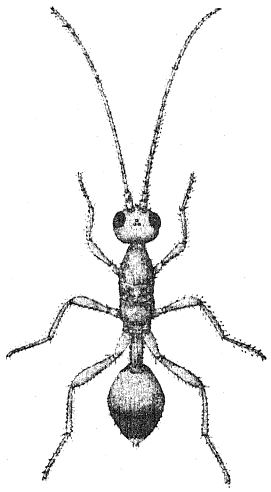


FIG. 3. Micropterous male (×12½)

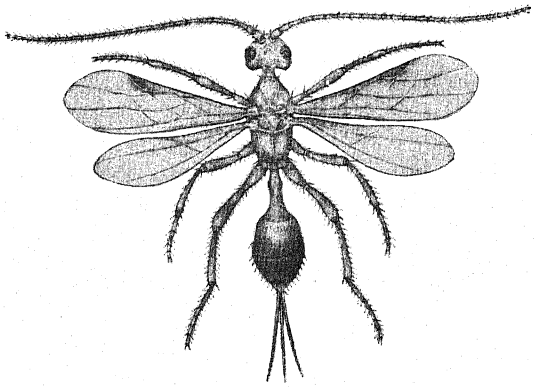


FIG. 2. Macropterous female (×13)

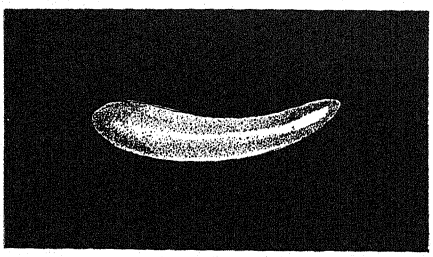


FIG. 1. Egg (×200)



FIG. 2.
1st stage larva (×42)

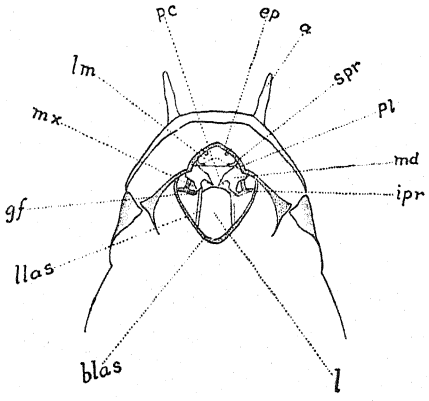


FIG. 3. Mouth-parts of 1st stage larva

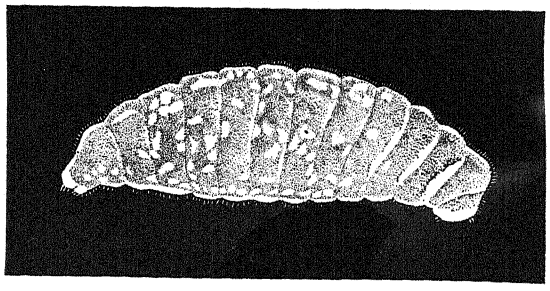


FIG. 4. Full-grown larva showing urate granules (×18)

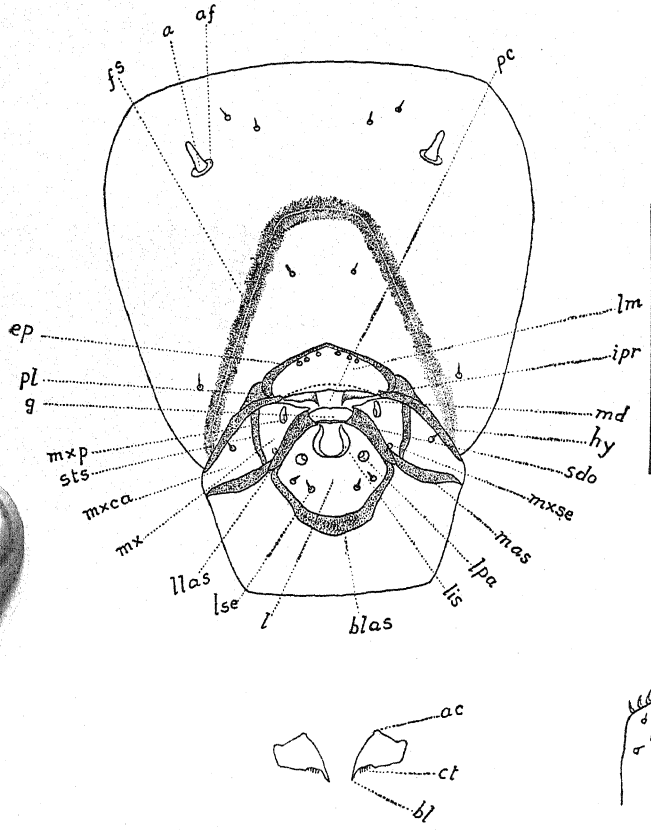


FIG. 5. Head and mouth-parts of full-grown larva (ventral view)

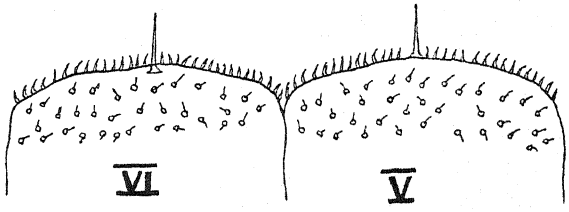


FIG. 6. V and VI segments of full-grown larva showing setal disposition (dorsal view)

[a=antenna; af=antennal foramen; ac=mandibular acron; blas=basal labio-stipital sclerome; mxca=maxillary cardo; ep=epistoma; fs=frontal suture; gf=glenoid fossa; hy=hypostoma; ipr=inferior pleurostomal ramus; l=ligular region; llas=lateral labio-stipital sclerome; lis=ligular sclerome; lm=labrum; lpa=labial palpus; l se=labial seta; mas=maxillary sclerome; md=mandible; mx=maxilla; mxp=maxillary palpus; mx se=maxillary seta; pc—preoral cavity; pl—pleurostoma; sdo—silk duct orifice; st s—stipital sclerome.

MANDIBLE

bl=blade; ac=acron; ct=comb-like teeth (denticles)]

appear more prominent when viewed under a binocular. Two dorsal rows of longer hairs are seen one on either side of median line. Length ranges from 1·6 mm. to 2·35 mm. averaging 2·17 mm. for ten specimens. Width ranges from 0·5 mm. to 0·725 mm. averaging 0·615 mm. for ten cases. Width of head ranges from 0·25 mm. to 0·275 mm. averaging 0·255 mm.

IV and final stage larva.—Size is very variable (Plate XLIII, fig. 4) depending on various factors particularly nourishment. Length 2·725 mm. to 4·32 mm. averaging 3·3 mm. for 13 individuals. Width 0·9 mm. to 1·45 mm. averaging 0·35 mm. Width of head 0·30 mm. to 0·45 mm. averaging 0·35 mm. Length of antennæ varies from 0·02 mm. to 0·025 mm. averaging 0·022 mm. for nine cases. In general shape, this and the previous stage are more or less similar. It is crescent shaped in its lateral aspect and is typically hymenopterous in form with a distinct head followed by 13 segments. It is widest in the middle tapering bluntly towards extremities. The general colour is still yellowish with a dirty brownish yellow mid-intestine. The granular urate cells show themselves more prominently. The segmental transverse lobes are more pronounced imparting a slightly flattened appearance. The body has a smooth appearance but under a binocular appears to be closely set with numerous minute setæ or spines.

Head.—In rough outline it has the appearance of a truncated heart with a sort of chin below. The truncated cone-like antennæ are larger and are placed on cuticular disc-like elevations. The integument is more chitinised and hard than in the early stages. The buccal organs (Plate XLIII, fig. 5) are visible and well defined. The upper lip is a thin semi-circular membrane partially covering the mandibles. The mandibles are more heavily chitinised, larger and sharper. They are disposed horizontally and are directed inwards and downwards. These bear five small comb-like denticles on the posterior edge; the maxillæ are membranous having a pair of maxillary palps. The labium is transparent bearing sensorial setæ. The salivary duct opens at the apex of the labium.

Body.—Body consists of 13 segments. Each segment has a number of fine, short setæ with a median long hair three or four times as long as the setæ (Plate XLIII, fig. 6). These hairs are so arranged as to form a dorsal median longitudinal row among the tegumentary setæ. The nine spiracles are clear and are located in slight depressions near the anterior border of the corresponding segment. The respiratory system as usual is made up of two longitudinal trunks connected anteriorly and posteriorly by transverse commissures. Each lateral trunk is connected to the spiracles by spiracular branches. At the root of each spiracular branch there are fine branches proceeding both dorsally and ventrally. These are seen to ramify extensively.

Larval development.—The parasites fail to develop when they are transferred while young to a non-paralysed healthy grub with mangled mouth-parts. Such hosts soon get diseased, darkened or fungus attacked. On transferring a parasite larva from one paralysed grub to another, normal development followed. Normal development does not take place when host-grubs killed in hot water are substituted. The entire question of development is governed not only by the quantity of food afforded but also quality and a paralysed larva constitutes the best medium.

Cocoon

The full-grown larva stops feeding, leaves the host remains and in about 24 hours starts spinning a cocoon about itself in the same tunnel in some suitable spot. This silken cocoon is perfectly white in colour. It is more or less uniform forming a complete parchment-like covering for the larva. The shape is not always uniform in cages. It is generally cylindrical and tubular in outline in nature but may be slightly short or loose or rhomboid in cages. When disturbed at this stage, the larva may enter into prepupal and pupal stage outside such cocoons or fail to develop further. In paraffin cells and gelatin capsules the cocoon was usually much thinner and sparsely lined with threads. In a small percentage of such cases no cocoon worth the name was spun and pupation occurred naked. Larvæ confined in tubes and flat surfaces on depression slides very often did not spin any cocoon except having a few loose threads thrown out irregularly. Apparently the walls of the tunnel, bark or any rough surface are required for scaffolding. The time taken to complete the covering averaged between 10 and 15 hours in a dozen cases noted. In about six hours a thin covering is more or less completed and the larva is barely visible through the cocoon. The female cocoons were slightly larger than those of males. Average length and width of 33 female cocoons were 5·5 mm. and 1·6 mm. The average length and width of male cocoons were 4·7 mm. and 1·5 mm.

Prepupa

Shortly after the completion of the cocoon the larva enters into the prepupal stage, having cast off the meconium in the shape of a brownish-dark mass at the posterior end of the cocoon. The larva does not undergo any material change except that it is motionless and slightly shrunken in size save at the thoracic portion.

Pupa

Just prior to pupation the last larval cuticle splits and is slipped off to the posterior end of the cocoon. The pupa at this stage is creamy white with even the eyes white. In a day the pigment appears first on pronotum and head. In another two days the eyes turn pinkish. The appendages are held loosely attached to the body. The pupa soon turns slightly yellow, becomes brown in another day and acquires the outline of the adult segments as also its colour and shape.

Emergence of the adult

When the pupa reaches maturity the fully formed adult becomes active and movements of head, antennæ and front legs may be seen. A small irregularly circular aperture is eaten at the anterior end of the cocoon a little on the dorsal or lateral aspect and the adult emerges out of the cocoon into the host tunnel. After gnawing a small rounded aperture through the bark or stem the adult makes its final exit into the outside world.

LIFE-CYCLE

The data on life-cycle periods were obtained from individual rearings from egg to adult in paraffin vials, gelatin capsules or in cells hollowed out in small bits of cotton stems confined in tubes. Life-cycle periods have been thus recorded for over 200 adults during 1936-37. Table II presents complete data for several stadia in relation to sex and host.

TABLE II

Parasite stage	Duration of range in days	Average in days	No. of cases
Egg period	1-2	1·2	26
Larval period, females	3-8	4·77	13
Larval period, males	3-7	4·64	11
Pre-pupal period, females	1-3	2·3	9
Pre-pupal period, males	1-3	2·75	4
Pupal period, females	5-13	8·6	12
Pupal period, males	5-10	7·5	4
Total period of females from egg to adult during April to December 1936 on *Pempheres*	12-19	16·0	37
Total period of males from egg to adult during April to December 1936 on *Pempheres*	11-20	14·3	51
Total period of females from egg to adult during April to December 1936 on *Hypolixus*	17-27	19·9	46
Total period of males from egg to adult during April to December 1936 on *Hypolixus*	13-28	18·7	35

TABLE III

Data on life-cycle periods on the host Sinoxylon sudanicum *during the months July to September 1936*

Parasite stage	Duration of range in days	Average in days	No. of cases
Egg period	1-2	1·3	6
Larval period	4	4·0	5
Prepupal period	1-2	1·8	5
Pupal period	7-10	8·4	5
Total life-cycle from egg to adult, females	13-18	17·2	15
Total life-cycle from egg to adult, males	14-18	17·0	45

The total life-cycle duration showed slight variation during the three different months.

The parasite has also been successfully reared on another host, i.e. on mature grubs of pulse bruchids, *Bruchus theobromæ* L. The rearing technique was the same as in other hosts. The total life-cycle period from egg to adult in June-July 1936 occupied about 18 days for both the sexes.

Seasonal variations in life-cycle periods.—For about 270 parasites consisting of males and females reared individually on different hosts during the period 1936-37, the life-cycle periods have been carefully recorded. The figures represent the averages of life-cycle periods worked out for several males and females during all the weeks of the month.

TABLE IV

Seasonal variation in life-cycle duration, in days, on different hosts for males and females, 1936-37

Month	1936						1937	
	Pempheres		*Hypolixus*		*Sinoxylon*		*Hypolixus*	
	Females	Males	Females	Males	Females	Males	Females	Males
	days	days	days	days	days	days	days	days
April	13·1	13·0	..	13·0	..	..	13·4	13·6
May	14·4	13·8	16·2	..	..	..	15·2	14·6
June	17·8	14·2	20·0	..	..	..	18·0	18·5
July	16·5	16·7	19·0	16·6	16·7	15·9	19·5	19·5
August .	..	..	..	..	18·0	18·0	16·2	18·3
September	..	..	18·6	16·0	17·0	17·0	20·8	17·5
October	..	..	19·6	18·0	..	..	18·7	17·5
November	18·0	16·0	20·9	19·2	..	..	19·0	20·5
December	..	..	22·0	20·0	..	..	19·0	27·0

The records of rearings on *Hypolixus* in the year 1937 show that the males have a slightly longer life-cycle period than the females.

Effect of climatic factors on the life-cycle.—For the years 1936, 1937 and part of 1938, the mean temperatures and humidities have been presented in a graphical form in Figs. 1 and 2. The months of March, April and part of May happen to be hottest periods of the year when the temperature is at the highest (mean 89·5°F.) with a low mean humidity of 52·7 per cent to 56 per cent. The development of the parasite is seen to be the quickest at this period with the shortest duration in the egg, larval and pupal stages. The life-cycle period reaches a minimum of 11 days with a maximum of 14 days in April averaging 13·5 days for about a dozen individuals reared. With the advent of monsoon in the latter part of May though the temperature is still high, there is a rise in humidity to some extent. The duration of life-cycle ranges between 13 and 16 days averaging about 14·9 days for 19 individuals reared during the month. In June there occurs a sudden fall in temperature from 89·5 to 82·0 with a rise in humidity from 56·9 to 66·3 per cent and the life-cycle period ranges from 16 to 20 days averaging 18 days. From July to November there is a gradual fall in temperature with an increase in humidity. The

former drops down to 77°-78° F. and the latter rises to 73 per cent in November with slight fluctuations. The life-cycle, therefore, gets prolonged from about 15 days in May to about 24 days and 27 days in November-December. There are slight fluctuations in the weather conditions during the months, such as a warm spell or heavy rains and these are more or less reflected in the slight reduction or prolongation of the duration of the life-cycle from 17 to 27 days as may be seen from Table IV. Leaving out the exceptional increase in humidity to 73·3 per cent in November, it may be noted that the variations in humidity during the months of June to December are found within the brief limits of 65 per cent to 68 per cent, whereas the deviations in temperature are slightly more pronounced as is manifested by the fall from 82° to nearly 77° F. It may be inferred, therefore, that the temperature perhaps is the more dominant of the factors in controlling the duration of the stages although the humidity factor is seen to exert its influence by either accentuating the former's effect by a decrease or considerably diminishing the same by a sharp rise. The data recorded from the rearings in 1937 confirm the above observations. During the cooler months the incubation is prolonged from one to two days, the larval period from three to eight days, the prepupal period from one to three days and the pupal period from 5 to 13 days. Excess of humidity manifests itself in an increase in fungus diseases or in the rapid multiplication of the predaceous laboratory mite *Pediculoides ventricosus* Newpt. This mite has been a constant menace in the laboratory in spite of all precautions.

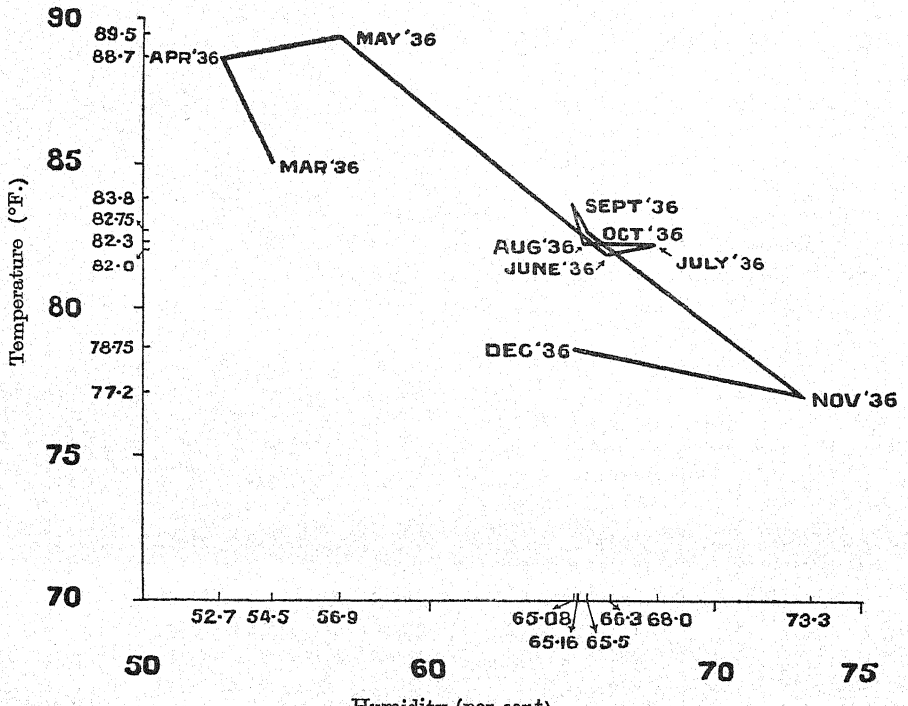


FIG. 1. Temperature-humidity, curve, 1936

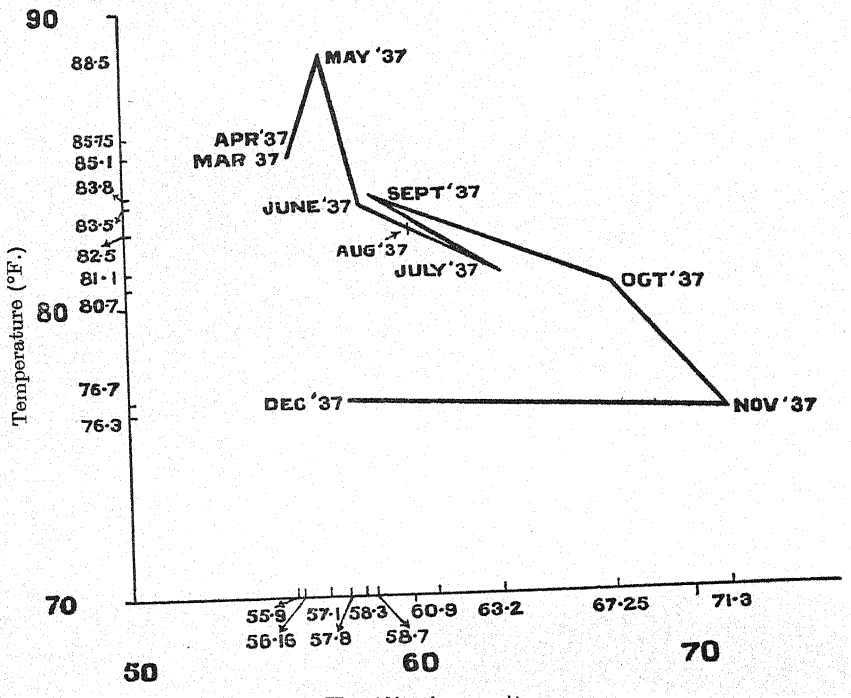


FIG. 2. Temperature-humidity curve, 1937

HABITS OF THE ADULT

This species seems to be active both during day and night as seen from its behaviour in large outdoor breeding cages. During the bright sunny hours of the day they seem to take shelter in shady hiding places. These often rest on underside of leaves or in crevices in soils. The best time for their easy collection from outdoor cages has been during evenings just before sunset when they can ordinarily be pushed into tubes by small brushes. They are essentially shade-loving and are in a way negatively phototropic as they readily move away from parts of tubes exposed to sunlight. Even winged adults pursue a zigzag flight and take rest away from lighted windows. They feed with avidity on nectar of flowers and are able to live for long periods as evidenced from their longevity records when fed on cotton flowers. Probably in nature their usual and natural food is nectar of flowers. They are also capable of living and reproducing to a slight extent without any food whatever.

Reactions to climate.—In outdoor cages and in open pits in fields while breeding on Bostrychids in cotton stalks, their activities are at the minimum during rainy days. No collection has been possible for some days after rains. They also dislike wet surfaces. Sometimes they display a peculiar habit of feigning death. When suddenly disturbed or shaken in a cage or forced to drop down, they remain still and motionless for a time as if dead, on their back with extended antennæ, but resume activity in two or three minutes. The activity of the males differs considerably from that of females. They either move about quickly in cages in search of females or for nourishment

They may also rest quietly for hours together on sides of cages, on stems or muslin covers and plugs

Parthenogenesis.—Virgin females after the usual pre-oviposition period readily oviposit and such eggs are seen to have a normal development. The progeny in all known instances of parthenogenesis invariably happened to be males. Eight virgins laid a total of 183 eggs out of which 24 adults (or 13·1 per cent) developed, all being males. Whereas the percentage of eggs that successfully developed out of 34 mated females was slightly higher, i.e. 19·6. Such variations may have been influenced by factors other than non-fertilization.

Occasional production of winged forms.—It has been observed that a small proportion of winged forms, particularly among the females appear occasionally which is a highly desirable feature for facilitating dispersal. Out of a total collection of 2,482 females there were only 272 winged (10·9 per cent). Winged forms among males have been very rare and only one winged form has been, during this long period, reared in the laboratory. Winged forms have been reared among the progeny of wingless ones.

Adult longevity.—These parasites are hardy insects which can stand strain and adverse conditions. Their longevity under optimum ecological conditions provided in the laboratory is seen to extend over five months (over 160 days). In order to study the relative length of life of the species, an extensive series of experiments running over several months during 1936-37 was conducted with a supply of various kinds of food. Nearly 300 adults of both the sexes, mated as well as unmated, mated females allowed to oviposit and otherwise, were experimented upon. Each individual was confined in a separate cage with a daily supply of the particular kind of food and daily observations were made until its death. The results are briefly summarised as follows :—The maximum record of longevity has risen to 162 days for an unmated male fed on nectar of cotton flowers. Unmated females have also lived up to 160 days on sugar solution. Such lengthened periods of life have been noted in a greater number of females than males. It has also been evident that unmated adults of both sexes generally show greater longevity than mated ones, the maximum for mated females and males being only 112 days each. The females are much more hardy and have been noted to live for pretty long periods even without food. The males on the other hand live only for a maximum of eight days without food. The greatest longevity, varying between 100 and 162 days, has been obtained with foods like cotton flowers, sugar solution, honey solution and raisin. In the matter of flowers, those of cotton appears to be the best among the few tested. The maximum longevity with cotton stems alone reaches 39 days. Females caged with a mere supply of host stages in cotton stems showed a maximum period of 39 days. This observation probably serves to prove that the adults do not feed on the body fluids of the host. With a daily supply of host stages in stems and food in the shape of honey, sugar solution or raisin the female longevity varied from 32 to 124 days averaging 61 days for 51 individuals.

Mortality in laboratory rearings

There are numerous factors that govern the rate of multiplication of the parasites in laboratory breeding experiments. Out of a total of 882 eggs laid

by a batch of 34 females it is seen that only 173 (19·6 per cent) adults successfully developed. The population increase during the first generation per 100 females comes to only 520 adults and only 53 per cent of these (i.e. 276) are females. But it has to be borne in mind that these factors may not necessarily be operating in nature and that the rate of increase under natural conditions may be consideraby higher than that observed under artificial conditions in the laboratory.

Total efficiency of the parasite

For 57 females tested in this series a total of 1,297 eggs were obtained, or 22·8 eggs per female. In other words every female by actual oviposition destroyed on an average (taking one egg per host as normal) nearly 23 hosts. Besides these, the same 57 females destroyed a total of 755 hosts by a process of mere stinging and paralysation which works up to 13·2 hosts per female. Every female, therefore, is seen to have actually destroyed on an average 56 per cent more of hosts than are oviposited upon. This is admittedly an important attribute of an efficient parasite which has to be taken into account when evaluating its total efficiency in nature.

Natural parasitism of the species in cotton fields, 1935-38.—For nearly three seasons during the period 1935-38, records of natural parasitism at the Cotton Breeding Station have been maintained as a routine part of the work. A few records have been obtained from other areas, such as Srivilliputhur in Ramnad district.* Thousands of cotton plants were collected and individually examined for every season so as to record the percentage of parasitism in relation to pest incidence. The rate of parasitism of this species alone has been always low and has never been seen to exceed one per cent (May, 1936). But one important point that has to be borne in mind is that this is the only parasite that occurs in some numbers during the first generation of the pest.

MASS-BREEDING OF THE SPECIES IN THE LABORATORY AND LARGE OUTDOOR CAGES

Scarcity of *Pempheres* during the greater part of the year necessitated an assiduous search for alternative hosts. A systematic and extensive collection and caging of all common stem borers and others belonging to various families, such as Curculionids, Cerambycids, Bostrychids, Bruchids, etc. was pursued. As a result, two alternative hosts were discovered—the common amaranthus-stem borer, *Hypolixus truncatulus*, and the Bostrychid borer attacking Cambodia stem, *Sinoxylon sudanicum*. The former weevil is a common borer of the weed amaranthus which is available in plenty at all seasons of the year. Though a convenient laboratory host, it was soon found that this host will not admit of any large-scale breeding of the parasites except for maintaining a small laboratory stock of the species. The other host was not very amenable for laboratory manipulation. By experiments it was discovered that green Cambodia plants pulled out and kept exposed in the open for two to three days served to attract these insects. This discovery proved to be of considerable use in an attempt at mass breeding. After a few experiments in the laboratory in small cages, large outdoor cages were devised

* The writer is thankful to Mr V. Margabandhu for the data from Ramnad district.

TABLE V

Spathius critolaus—*occurrence in nature*

Months	1935			1936			1937		
	Percentage of pest attack in live plants only	Percentage of total parasitism	Percentage of *Spathius* parasitism	Percentage of pest attack in live plants only	Percentage of total parasitism	Percentage of *Spathius* parasitism	Percentage of pest attack in live plants only	Percentage of total parasitism	Percentage of *Spathius* parasitism
January . . .	..	..	..	55·0	2·6	0·51	82·7	1·20	*nil*
February . . .	..	..	..	74·0	2·6	0·26	89·9	0·67	*nil*
March . . .	..	..	..	91·7	11·3	0·83	35·2	1·00	*nil*
April . . .	..	..	..	88·2	1·7	*nil*	66·0	0·32	*nil*
May . . .	..	..	..	98·7	3·0	1·0	82·3	0·32	0·16†
June . . .	..	..	..	99·1	*nil*	*nil*	99·8	6·80	0·07†
July . . .	..	..	..	100·0	*nil*	*nil*	89·1	3·80	*nil*†
August . . .	..	..	..	100·0	*nil*	*nil*	100·0	2·70	0·04†
September . .	..	..	..	..	..	..	..	..	..
October . . .	97·4 23·1	1·3 1·7	0·39* *nil***	..	..	..	12·85	1·00	*nil*
November . .	18·4	1·4	0·61	4·7	0·74	0·37	11·90	10·47	0·47
December . .	28·4	*nil*	*nil*	67·9	0·22	0·22	15·50	*nil*	*nil*

* Srivilliputhur area. ** Coimbatore area.

† These data were obtained from an off-seasonal crop sown in February 1937.

and substituted for the purpose. Large collections of fresh and slightly wilted cotton stalks were first stocked in such cages. Bostrychid adults were secured either from infested cotton stalks found in nature or by attracting the same to wilting plants kept exposed for the purpose. These beetles were introduced into the cages and allowed to bore and breed in the fresh material provided. After a period of about three weeks, when by examination the right types of host-grubs were found to occur, mated female parasites were liberated in the cages from the laboratory stock. In a fortnight to three weeks after liberation, adult parasites continued to emerge. This process was continued without interruption by artificial manipulation of the host so as to produce overlapping broods. The problem of the scarcity of *Pempheres* stages was thus partially solved. As many as 4,759 parasites have thus been bred.

Proportion of sexes

The proportion of sexes for a total collection of 2,732 adults from outdoor cages in 1936 was 52·4 per cent females and 47·6 per cent males. The winged forms among females work to 11·4 per cent. For a catch of 2,127 adults in 1937 the proportion of females to males was 56·4 per cent to 43·6 per cent. Winged females formed only 7·7 per cent among females. There was a solitary instance of a winged male in the rearing.

The proportion of males to females varied within a wide range during the different months. From 57·7 per cent females in March 1936 the number dwindled to 23·9 per cent in July. Thereafter these were on the increase. From 31·4 per cent in August the percentage rose to 63·7 per cent in December. From almost equal proportions in January 1937 the females dwindled to 37·8 per cent in April which gradually ascended to 60 per cent in December. As is the case with a number of other parasites, an automatic adjustment of the proportion of sexes is evident in this species with a view to ensure maximum reproductive capacity. When the proportion of females is large, i.e. when females are considerably in excess of males, parthenogenetic reproduction ensues in a large percentage producing only male progeny so as to raise the proportion of males. With the increase in males the females undergo a reduction in numbers. With increased opportunities for all females to get mated their productivity is increased and the females gradually rise in numbers so as to gain their normal proportions. It is not known whether such oscillations in the proportion of sexes is influenced by other factors, such as abundance or size of hosts, etc.

Experimental releases and recoveries in large field cages.—In order to gauge the possibility of increasing the efficiency of the parasite in nature, a few experimental releases of parasites in field cages were attempted. As pointed out already the parasite makes its appearance in the field during the first generation of the pest when the percentage of infestation is low. At this period the host-stages are not located far away from the surface of stems since the plants, being young, possess only thin and slender stems. Paucity of parasites at this period could be artificially remedied to some extent by keeping ready a stock of parasites by mass-breeding and liberation at the right time. A few experimental releases were planned and tried during the period. A preliminary trial in cages was attempted early in 1937 but this was vitiated since

the caged plants were heavily covered with ants, aphids and coccids. Since the parasites were readily attacked by the ants, this experiment was abandoned and a second trial was conducted in another cage towards the close of 1937. Plants were grown in this cage during September 1937. These plants were artificially infested by the introduction of a sufficient number of weevils. As weevils bred in cotton were not available at the time those obtained from alternate host plants, like *Triumfetta rhomboidea*, were utilized for infestation. It was later on discovered that only a very small proportion of the weevils had oviposited on these cotton plants. The infestation, therefore, was not heavy and the host stages were scarce. Yet liberations of parasites were made from November onwards till February 1938. Since only a small percentage of plants was found to be infested, only such plants as were, by external scrutiny, noticed to be attacked by a weevil were pulled out and examined month after month. The results of these examinations are presented in Table VI. From the figures it may seem that the infestations and percentages were sometimes high but the live stages happened to be comparatively few. The percentage parasitism was worked out on the basis of live and dead stages together as also on total infestations.

TABLE VI

Parasite releases and recoveries in cages

Months	No. of parasites released	Per cent of weevil attack	Percentage parasitism		Remarks
			As per stages	As per total infestations	
1937					
November	121	91·7	58·3	38·9	Live stages available for parasitisation were always much fewer than the infestation percentages might apparently indicate.
December	48	91·7	20·0	6·3	
1938					
January	23	100·0	21·4	17·6	
February	4	100·0	60·0	33·3	

It may be pointed out that no satisfactory conclusions can be deduced from this experiment owing to the development of the unexpected handicap mentioned already. It may, however, be inferred that a higher rate of parasitism can probably be induced in nature by repeated and large-scale releases of parasites at the proper time.

POTENTIALITIES

The life-cycle of the parasite covers normally a little over two weeks, whereas the pest multiplies comparatively slowly under field conditions having

a very long life-cycle occupying nearly seven to eight weeks. The parasites can theoretically accomplish nearly three generations before the host completes one. The average reproductive capacity of the parasite appears to be in no way inferior to that of the pest. Though the maximum egg capacity of the weevil, as recently observed, may rise as high as 164, the average capacity seldom goes above 24 eggs per female under optimum environmental conditions. The parasite on the other hand possesses an average capacity of 22 to 24 eggs. Considering the numerical equality in the proportion of sexes, the parasite can multiply rapidly and attain abundance in a short period so as to overtake the pest. Yet the rate of natural parasitism in cotton field conditions has never been seen to rise over one per cent. This may be due to a number of handicaps. The first and foremost among these may be located in the inherent habits and habitats of the pest. The most vulnerable part of its life is spent within the protected situation of the woody stem which is comparatively inaccessible. To some extent this handicap may be overcome by the presence of a comparatively long ovipositor in this particular species of parasite. A far more serious limitation is the restricted choice of victims. Parasitisation is possible only on a particular stadium in the life-cycle of the pest. Only medium-sized and mature grubs of the weevil are capable of being parasitised—the earlier and later stages being comparatively immune and the parasite may have to remain idle for long or short periods on account of the absence of the appropriate stages. Compensation for this to some extent may be found in the lengthened larval period and uneven development of the host, whereby, even in the first generation, grubs of varying ages may be found for long periods. In later generations considerable overlapping of broods occurs and suitable stages may be available at least in small numbers at all times. It is natural that such host stages may lie scattered in different plants located at short distances from one another. The parasite may not be able to explore any large area as it possesses only vestigial wings. This is another handicap operating against quick dispersal which is however mitigated to a great extent by the occurrence of a small percentage of winged forms, particularly among females. Another, perhaps more serious, difficulty is that the cotton season normally closes by the end of March, i.e. during the third generation of the host. By this time the live population of the weevil has already dwindled to very small proportions and to add to this the entire crop is removed and the parasite is confronted with the problem of tiding over the off-season. The entire absence of host stages in nature may constitute another drawback in its continued multiplication. This difficulty can be easily overcome in more than one way. Fortunately the adult life of the parasite is considerably prolonged, extending over five months under favourable conditions. It can therefore even survive a waiting period. Besides, the parasite can continue in nature at least in small numbers without extinction in an alternate host, like *Hypolixus*, which is available at all seasons. It can also maintain a small population on *Pempheres* itself which is now known to have a variety of alternate host plants. Many such alternate host plants have yielded this parasite, though in small numbers, in a variety of situations. Far more important than any of these is the facility afforded by the Bostrychid—*Sinoxylon*—for its easy multiplication so as to tide the off season. This Bostrychid freely breeds in wilting

Cambodia plants as also in those pulled out and stacked near cotton fields. By artificial manipulation of the broods, suitable stages for parasitisation can be continuously made available for pretty long periods.

Further there are a few other attributes of the parasite which are highly conducive to its efficiency. The occurrence of the parasite in most localities where the pest is found and its capacity to attack *Pempheres* in very nearly all of its alternate host plants is decidedly to its advantage. The parasite, so far as has been ascertained, is free from the attentions of any secondary or hyperparasite. Its capacity to destroy more hosts than are actually oviposited upon is another point in its favour. The discrimination displayed in the choice of the host from among healthy active ones and the economy practised in its oviposition tend to enhance its efficiency. Its eggs are evenly distributed and over a larger number of hosts and the wastefulness of many a parasites is eschewed. Its crowning attribute is that it attacks the pest in its first generation when the incidence is very low. The majority of host stages are easily accessible being nearer the surface in the stems because the plants at this stage are very young, tender and thin. Even a small percentage of mortality caused at the beginning of an outbreak is very effective because the weevil is known to multiply and build up its heavy population more by continuous breeding on the same crop rather than by any wave of immigrants. Since parasitism is restricted to only full-grown grubs it might be argued that the parasite begins to operate a day after the fair when the pest has completed its damage. This might be true in the case of other pests but not of this weevil. The initial percentage of incidence of this pest is usually low and the damage caused in the beginning of the season, though not negligible, is not appreciable. It is the potential increase of the damage as the generations advance that is a real source of danger which requires to be warded off. But the percentage of parasitism in nature at this stage is too low and inefficient to arrest the multiplication and spread of the pest. Yet the utility of even this small rate of parasitism cannot be ignored in the maintenance of the balance in nature. The problem is that in spite of possessing such favourable attributes it is still not an effective parasite in the field. The reason may be that the parasites are not numerically strong during this critical time which defect can be rectified by artificial means and the percentage parasitism increased as in experimental cages. The question of enhancing the efficiency of an indigenous parasite in its native environment is a great experiment in an unexplored line of investigation in this country; and the present studies, despite the knowledge gained so far, are yet preliminary. There are a few instances of success in other parts of the world. The parasite certainly has possibilities and extensive trials with the parasite are worth making though success is not assured.

ACKNOWLEDGEMENTS

The writer wishes to record his indebtedness to the Bureau of Entomology, Washington, and the Imperial Institute of Entomology, London, for the identification of the parasite. He also wishes to express his gratitude to the Indian Central Cotton Committee for making the investigation possible by rendering the required financial assistance. The writer's special thanks are due to all his colleagues who have assisted him in various ways throughout this investigation.

REFERENCES

Genieys, P. (1925). *Ann. Ent. Soc. Amer.* **18**, 143-202

Jones, D. W. (1929). *U. S. Dept. Agric. Tech. Bull.* **98**

Myers, J. G. (1927). *Bull. Ent. Res.* **23**, 211

Nixon, G. E. J. (1939). *Bull. Ent. Res.* **30**, 119

Parker, H. L. (1931). *U. S. Dept. Agric. Tech. Bull.* **230**

Ramakrishna, Ayyar T. V. and Margabandhu, V. (1936). *Madras Agric. J.* **23**

Salt, G. (1932). *Bull. Ent. Res.* **23**, 211

——— (1934). *Proc. Roy. Soc.* (*Lond.*) (**B**) **117**, No. 413

Smith, H. S. and Compere, H. (1926). *California Univ. Pub. Ent.* **4**

Thompson, W. R. and Parker, H. L. (1926). *U. S. Dept. Agric. Tech. Bull.* **59**

——————————————— (1927). *Parasit.* **19**, 1-34

Timberlake, P. H. and Clausen, C. P. (1924). *California Univ. Pub. Ent., Tech. Bull.* **3**, No. 2

Ullyett, G. C. (1936). *Proc. Roy. Soc.* (*Lond.*) (**B**) **120**, No. 817

Wilkinson, D. S. (1931). *Bull. Ent. Res.* **22**, 259

THE ROLE OF FOOD AND ITS CONSTITUENTS ON THE PRODUCTIVITY AND LONGEVITY OF THE COTTON-STEM WEEVIL, *PEMPHERES AFFINIS* FST.

BY

P. N. KRISHNA AYYAR

AND

V. MARGABANDHU

Agricultural Research Institute, Coimbatore

(Received for publication on 4 March 1939)

(With one text-figure)

INTRODUCTION

ALTHOUGH *Pempheres affinis* has been the subject of study for many years, and considerable knowledge has been accumulated on its general biology, comparatively little is known of the power of reproduction of the adult female. This is indeed surprising since it is the adult female's habit of oviposition on cotton that makes for its numerical abundance, destructiveness and economic importance.

It is recognised that physical conditions exercise a profound influence on the physiological activity of any insect, including its oviposition. The writers carried out some studies on the behaviour of *Pempheres* under controlled conditions of temperature and humidity*. In the course of such studies, considerable new light was shed on its ovipositional response. It was noted that its fecundity was increased to enormous proportions with a supply of certain kinds of foods, the physical conditions remaining the same. This observation led the writers to feel the imperative need of studying the nutritional physiology of the weevil, particularly in relation to its productivity. Such studies are deemed to be capable of yielding results of practical importance. They may afford clues for its successful control.

It is observed that some work has already been done on the subject of insect dietetics. These have been summarized by Uvarov [1928]. Among such contributions those of Larson and Fischer [1925] and Norris [1934] may be considered as pioneer investigations. Recent researches have also been largely directed towards an analysis of the effect of individual constituents of food on insect physiology ; and contribution on this aspect is already on the increase. Among these, the investigations on *Agrotis*, *Pyrausta* and *Loxostege* by Kozhantshikov [1938], on *Lucilia* by Dorman *et al.* [1938], on *Rhagoletis pomonella* byDean [1938], on *Aphids* by Evans [1938], etc. form some of the more important contributions. Among Coleoptera it is only the Tenebrionidae, Bruchids and Dermestids that have received some attention in this respect. These notwithstanding, the problem of the role of food

*The results of these studies are embodied in a separate contribution by the authors.

and its constituents on the fecundity and longevity of insects may be regarded practically as a virgin field and particularly so in regard to the group of insects known as weevils.

These considerations served to bring into prominence the need for the study of the character and composition of food-requirements, both qualitatively and quantitatively, of *Pempheres*. Some experimental work was therefore started as a mere preliminary to such studies by the middle of 1938. In pursuance of such studies the oviposition of over 100 females has been studied with a variety of foods and more or less identical physical conditions between the period of July to December 1938. It is the purpose of the present paper to record the results of these studies.

Review of previous work on *Pempheres*

Previous records dealing with oviposition of *Pempheres* are scanty. The few general references on its life-history yield very little data on its fecundity. This may be partly due to the fact that egg-laying records of the weevil are difficult to obtain. The eggs are laid concealed in cavities especially made in the bark of plants often without external indications in the form of scars. The earliest workers such as Lefroy [1908], Fletcher [1913], Ramakrishna Ayyar [1918], etc. are more or less silent over this aspect. Ballard [1923] has recorded an average egg capacity of 15·5 eggs per female with an average longevity of 16·7 days per female with a maximum of 30 eggs per female qualified by the remarks that in nature the egg-laying capacity may be greater. The present authors in the course of trials with about 500 females (1937-38) under controlled physical conditions noted a maximum of 121 eggs per female during a maximum life span of about three months, the average egg-laying capacity per female being 46.

Methods of study

The methods employed in the study of this aspect on this weevil by the present authors and those by previous investigators appear to be different. In cases where plants were exposed to weevils for oviposition in fairly large cages, the maintenance of the live plant in condition in cages and the microscopic examination of all the plant-parts would appear to be very tedious and uncertain. In the present studies the weevils utilised for experiments consisted of newly emerged adults from caged cotton stalks. The cages employed were 6 in. × 1 in. glass tubes with mouths plugged with clean cotton. Mating took place frequently throughout their life. Previous experiments by authors have shown that no difference in productivity or fertility is produced by isolation of males after a day or two or more. Instead of supplying entire plants for oviposition, small bits of fresh cotton stalks less than an inch in length were introduced into these cages. These were almost regularly removed after 24 hours or longer intervals and examined by careful dissection under a binocular. The daily counts of eggs were recorded. Fresh bits of stalks were supplied in the same manner. The specific food selected for trial was introduced into the cage and removed daily. These cages were kept under uniform conditions of temperature, humidity and light in the laboratory. Daily records of these factors were also maintained. Any difference in the eggs laid or longevity observed in each such set was therefore attributable to the differences in the nature, composition and quantity of the food supplied.

Very little is known about the feeding habits of the adult female. That the main source of the food of the adult weevil is the stem of cotton is apparent from the feeding punctures caused in stem apart from those made for egg deposition. Whether the female supplements it by feeding punctures on any other part of the cotton plant in nature has not been investigated.

Experiments with different kinds of food

All the trials were carried out under almost identical conditions of temperature and humidity within a narrow range from 81° to 83° F. and about 73 per cent relative humidity.

The oviposition and longevity of the insect were tested with the following foods :

Experiment I

With no artificial food.—Twelve pairs were tried under this head. No artificial food of any kind was supplied. The adults were deprived of even water. A small bit of fresh cotton stalk about an inch in length was supplied as a medium of oviposition.

The females laid an average of 4·01 eggs with an average life-span of 9·01 days. The maximum number of eggs laid by a single female was about 20. The maximum longevity recorded is about 15 days. Nearly 33 per cent females failed to oviposit.

Experiment II

Without artificial food but with a supply of water.—Twelve pairs were under observation in this series. The average number of eggs laid per female was 4·3 with an average life-span of eight days. The maximum number of eggs laid by a single female was about 11. It was found that the productivity has not been improved upon by a supply of water. On the other hand, maxima recorded for oviposition and longevity have decreased to a small extent.

Experiment III

With a supply of sugar solution.—Only seven pairs of adults were under trial in this category. These were provided with a daily supply of sugar solution by means of cotton wool soaked in the same.

It may be seen that an average of 25·3 eggs per female was deposited with an average life-period of 53·7 days. The maximum number of eggs laid by a female was about 41 and maximum duration of life nearly 62 days. There was no instance of a female that failed to oviposit. It is evident from the data recorded that the effect of a sugar diet on longevity as also on fecundity is very pronounced.

Experiment IV

With a supply of sucrose solution.—Twelve pairs of adults were kept under observation with a supply of sucrose solution as food.

There was an average number of 16·7 eggs with an average duration of life of 52 days per female. The maximum number of eggs laid by a single female has risen to 35 with a maximum longevity of 91

days. A small percentage, namely 8·3, of females failed to oviposit. Sucrose which is 100 per cent carbohydrate and said to possess great life-sustaining value has provided interesting data demonstrating the effect of an exclusive carbohydrate nutrition. In regard to longevity though the average does not show an increase, it is clear from the maximum of 91 days that the life-sustaining function of this constituent is remarkable. It has also clearly brought out that the productivity is diminished in that the average and the maximum number of eggs laid are decidedly lower than those with a sugary diet.

EXPERIMENT V

With honey solution.—Honey which is made up of 81·2 per cent carbohydrate and 0·4 per cent proteins was provided as food for a set of 12 pairs.

It has shown an average of 19·1 eggs with an average life duration of 30·3 days. The maximum number of eggs laid by a single female was 47. These data are of considerable interest when compared with sucrose or sugar diet. Honey which contains a trace of protein has shown a slight increase in the average productivity over sucrose though decidedly less than that with sugar. In the matter of maximum egg capacity, honey has produced such a high number as 47 as compared with 35 and 41 by sucrose and sugar respectively. The average life however is considerably reduced on this diet in comparison with sucrose or sugar. In the matter of reproductive capacity correlated with duration of life, honey diet is seen to be definitely superior to sucrose or sugar.

EXPERIMENT VI

With jaggery as food.—Jaggery was provided as food in the form of solution in cotton wool for a set of 12 pairs.

With this diet which contains a small proportion of protein, namely 0·6 per cent, the life-span is seen to be considerably reduced in comparison with sucrose, sugar or honey. But the egg-laying capacity is seen to have appreciably risen in both the average and the maximum.

EXPERIMENT VII

With molasses as food.—A series of 12 pairs was experimented on with a supply of crude molasses as food. This contains a higher proportion of proteins as also of impurities.

Molasses with about 2 per cent proteins and 69·3 per cent of carbohydrates has shown interesting results. The life-span is considerably reduced together with a reduction in average fecundity as compared with any of the other foods. This is probably due to the large amount of impurities which renders it easily susceptible to fungus. It has however significantly brought out the influence of the protein constituent by an appreciable rise in maximum egg-laying capacity to as high a figure as 60.

EXPERIMENT VIII

With a supply of raisin.—With a supply of entire raisin as food 12 pairs of adults were experimented upon.

An enormous increase in both fecundity and longevity has been noted. There was an average duration of life of 67·5 days with an average of 76·0 eggs per female. The maximum number of eggs laid by a single female has

risen to a record figure of 164 with a maximum longevity of about 136 days. Raisin containing 2·3 per cent proteins, 3·0 per cent fat and 68·5 per cent carbohydrates seems to be so far an ideal diet for this species. The importance of this diet, especially nitrogenous part thereof, has been amply demonstrated by these experiments.

Oviposition sites

It is believed that Coleopterous insects require, in addition to a generous food supply, suitable oviposition sites for stimulating egg-laying to the maximum capacity. Since *Pempheres* adults always make a number of feeding punctures before oviposition, the choice of oviposition sites may be influenced by the suitability of the tissue in the spot as food for the adult. To some extent the suitability of a site may also be governed by the nature of food available at the spot for the development of the grub that hatches out of the egg. It is known that the nutriment obtainable by a weevil may not only differ with different species of plants but also with the various parts of the same plant. Such differences in composition are stated to exist between the vegetative, flowering and other parts of the same plant. In order to see if differences in the choice of oviposition sites are due to variations in food value for the weevil adults, a series of trials with the various parts of cotton plant, such as roots, tender bolls, etc. was made.

Experiment IX

Oviposition and longevity with a supply of roots.—In this experiment, only roots were supplied in cages. Twelve pairs of adults were tried.

Eggs were laid at the cut end of the root caps leaving scars similar to those caused on stems. The eggs were not thrust deep into the roots. The average number of eggs laid was only 1·1 with an average duration of life per female of 7·5 days. A maximum of six eggs is noted for a single female. Nearly 66·6 per cent of the females did not oviposit.

Experiment X

With a supply of flower buds.—Thirteen pairs were experimented with. The only parts supplied as food as also for oviposition medium were flower-buds.

The eggs were deposited at the calyx region buried inside the petals. Punctures were noticed on the sepals. There was an average longevity of 8·1 days per female. The maximum number of eggs noted for a single female was only about nine. 42·6 per cent of the adults failed to oviposit.

Experiment XI

With a supply of tender bolls.—In this case only five pairs were under observation. Oviposition in these trials was very profuse as in one instance nine eggs and in another seven were noticed in a day. Egg-layings were confined to the calyx region where the bolls were soft and succulent. Numerous punctures were seen—sometimes as many as 40. Eggs were thrust into punctures made in the calyx and buried in the boll flush with surface of the boll. These were in most cases unsealed and visible. There was an average of 6·75 eggs with an average life-span of 8·2 days. A maximum of 12 eggs was seen deposited by a single female. Nearly 20 per cent of the adults failed to oviposit.

TABLE I

Effect of different foods on the longevity and fecundity of Pempheres

No.	Nature of food	No. of trials	Average eggs per ♀	Maximum eggs per ♀	Average longevity in days per ♀	Maximum longevity in days per ♀	Average post-oviposition period in days	Duration of egg-laying period in days	Rate of oviposition
1	2	3	4	5	6	7	8	9	10
1	Without food or water	12	4.0	20	9·0	15	3·9	2·3	2·7
2	Without food but with water.	12	4·3	11	8·0	11	4·6	1·4	3·4
3	Honey solution	12	19·1	47	30·3	52	4·8	21·3	0·9
4	Sucrose	12	16·7	35	52·0	91	16·0	20·3	0·8
5	Sugar	7	25·3	41	53·7	62	12·0	42·6	0·6
6	Jaggery	12	31·1	47	20·7	24	3·4	13·0	2·3
7	Molasses	13	13·5	60	16·1	21	3·0	9·0	2·0
8	Raisin	12	76·1	164	67·5	136	13·3	45·4	1·5
9	Roots	12	7·1	6	7·5	11	4·5	1·5	2·2
10	Flower-buds	13	2·5	9	8·1	11	4·1	1·1	4·0
11	Tender bolls	5	6·8	12	8·2	14	4·3	2·0	3·4

Discussion

Interesting data of considerable significance has been obtained from the series of experiments just described. The physical factors of temperature, humidity, light, etc., under which the several experiments were performed being more or less identical, the only variable factor involved in the experiments was the character and composition of the food supplied. On a comparison of the results obtained with the various foods, a wide range of variation is produced in regard to productivity and longevity by the nutrition afforded. It is evident from this that the weevils under favourable nutritional conditions are able to draw out in full their powers of reproduction. Table I presents the summarised results of all the experiments which are also expressed diagrammatically in Fig. 1.

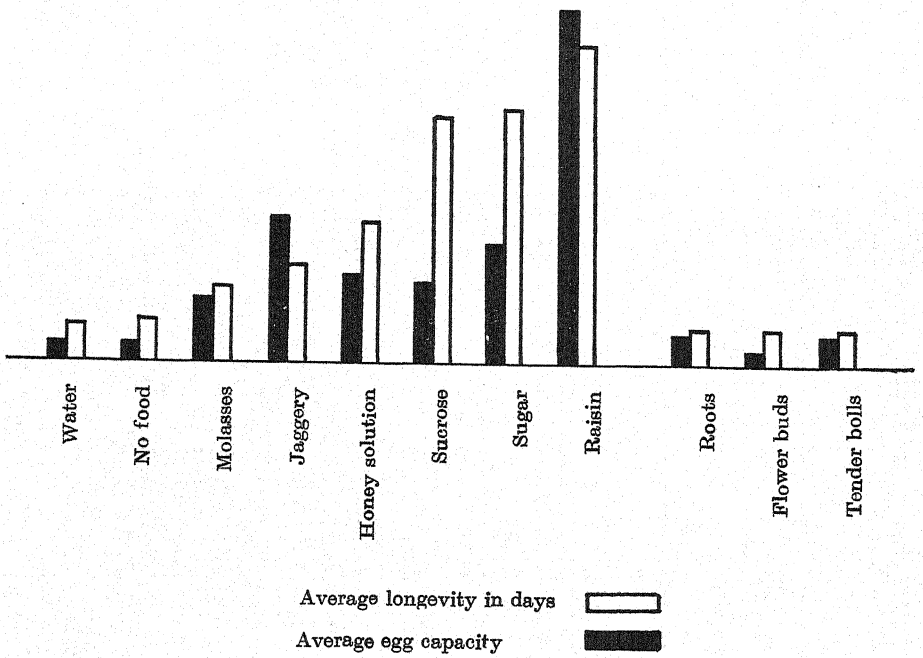


Fig. 1. Results of nutritional trials

Experiments without any supply of artificial food have shown an average of 4·01 eggs per female with an average life-span of 9·01 days. A mere supply of water produced an average of 4·3 eggs with a mean longevity of eight days. It is evident therefore that access to water has in no way increased the activities of the weevil. In the case of all the other experiments, a definite increase in both life-duration and egg-production is noticeable. It may therefore be inferred that both productivity and survival of the adult females are conditioned upon taking some food other than the cotton stalk supplied and that all the eggs are not developed at the time of emergence and the reserve of fat body does not suffice for full physiological functioning.

Leaving the experiment with raisin which is an extreme case, the other foods may be classed as predominantly carbohydrate in character. A comparison of the data on average egg-laying capacity with each of the remaining foods shows that jaggery stands foremost with 31·1 eggs, sugar coming next being followed by honey solution, sucrose and molasses in the descending order. The results assume a different aspect when the data of maximum egg-production are taken into consideration. Molasses with its slight protein content shows a maximum of 60 eggs and comes to occupy the first place ; jaggery and honey solution, each with a trace of protein, rank next and seem to have almost equal effect with 47 each ; sugar and sucrose which are exclusively carbohydrate foods come next in the series with 41 and 35 respectively.

On the other hand, the effect of these foods on the survival of the insects has yielded a different set of data. On the basis of average longevity those fed on sugar stand first with 53·7 days ; sucrose closely follows with a mean of 52·0 days. Sucrose—cent per cent carbohydrate—reveals the longest duration of 91 days. Sugar and honey appear to be the next best. Jaggery and molasses stand far behind the others in this respect. The length of life with the latter foods is much more abbreviated probably owing to the more rapid rate of oviposition in them as compared with sucrose, sugar or honey (Table I) wherein greater longevity does not proportionately enhance the productivity but only quicker exhaustion of the ovaries resulting in a prolonged post-oviposition period. Among the variety of diets tested in this series of experiments, raisin stands supreme and unique in the matter of mean as well as maximum longevity and oviposition. A record figure of 164 eggs is obtained as maximum with the highest average of 76·1 eggs and a longevity of 136 days or nearly 4½ months as maximum with 67·5 days as the average. It may be clear that no other food experimented with approaches raisin either in bestowing duration of life or egg-laying capacity.

It is evident from the results discussed that the explanation for such wide variation in productivity and life-duration is to be sought in the quantity and quality of the constituents of the diets. It is a generally accepted fact that the adult insects in general can sustain life on a carbohydrate diet but require proteins for the development of the genital products. Uvarov [1928] has summarized the literature on the subject and instanced several cases in support of the same. Mackerras [1933] experimenting on *Lucilia* has demonstrated the same. This is strongly supported by such phenomena in nature as the occurrence of voracious predators among females of several groups of insects and animals, by the habit of certain female hymenopterous parasites in feeding on the body-fluids of their hosts [Flanders, 1936]. The latter author has emphasised the great need of parasitic females for a protein diet since a carbohydrate diet is often available. It is generally recognised that no reproduction is possible without inclusion, at some time, of nitrogen in the diet. In the case of *Pempheres* the fecundity is not only increased by a nitrogenous food but also to a small extent by an exclusively carbohydrate diet. This is apparently in conflict with the results obtained by Norris [1934] in respect of *Ephestia* spp. She says that a diet of cane sugar increases the longevity of females of *Ephestia* but has no effect on its fecundity. Dean [1938] has arrived at the same conclusion in his studies on *Rhagoletis pomonella* (Apple maggot adults). He has found an increased number of eggs by adding

a protein food to sugar, while with sugar solution the length of life is increased but only a few eggs are laid.

The results obtained by the present writers are to a certain extent in conformity with those recorded by Larson and Fischer [1925] in their experiments with *Bruchus quadrimaculatus*. They have demonstrated that sugar feeding increases not only longevity but also fecundity. In the present trials the data show that a sugar diet has certainly augmented productivity besides life-duration over that obtained with no artificial food or with mere water. To this extent the writers agree with the findings of Larson and Fischer. Some of the latest researches on the subject seem to lend partial support to this inference. Kozhantshikov [1938] has proved that sugar nutrition in the case of *Agrotis* sp. and *Pyrausta nubilalis* has great influence not only on longevity but also on fecundity and fat reserves. Researches on the moth *Loxostege sticticalis* by Larchenko [1937] have shown that reserve fat is formed in the larval stage which is passed on to the adult stage in fatty tissue and supplementary feeding in itself does not provoke egg-maturation ; the latter is only possible when the fat body is dissolved and used by adult feeding. On the other hand Dorman *et al.* [1938] have shown that *Lucilia sericata* requires proteins for growth of ovaries and carbohydrate for long life of the adult stage. The data recorded by the authors with a raisin diet are in full accord with this finding.

The fundamental importance of a study of carbohydrate nutrition in general cannot be over-estimated since in nature large groups of insects are entirely dependent upon an exclusively carbohydrate food, like nectar of flowers. Such investigations would be of great interest, particularly in the face of such a conflict of opinions. In the absence of any further evidence it may be safe to conclude that while the effect of proteins in stimulating egg-production is undoubted there is evidence to show that carbohydrates are not without any importance in this respect. In the matter of longevity it is clear that a sugar diet has great influence in prolonging life.

From a study of the oviposition sites chosen by the weevil, some interesting though tentative conclusions can be drawn. Though *Pempheres* under pressure of circumstances may select any part of the food-plant for oviposition such as root, flower-bud, shoot or boll, oviposition is generally poor and life-span considerably reduced. It may therefore be inferred that though the weevil can utilise any part of plant as an egg-laying site, the necessary food and stimulus for development of eggs and continued life are not obtainable from these sites. These experiments also admit of the following inference. The cotton stem by itself is unable to supply either in quantity or quality some nutritional factor or factors necessary for normal egg-production which the weevil may perhaps be able to obtain from either other parts of the same plant or other species of plants. Further studies in the line are urgently needed for a fuller understanding of the problem.

Summary and conclusion

A series of experiments has been described to determine the effect of different kinds of food on the fecundity and longevity of *Pempheres* under nearly identical physical conditions. A convenient method of obtaining accurate oviposition record is given.

Table I is presented recording the results obtained in respect of various foods namely sucrose, sugar, honey, raisin, etc.

Mere supply of water does not seem to have any beneficial effect on its life-duration or reproductive powers. An exclusive carbohydrate diet is noted to produce a remarkable increase in longevity as also to a limited extent in fecundity. Molasses with its slight protein content has shown an increase in maximum egg-laying capacity over all foods except raisin. Raisin whose composition includes a small proportion of proteins and fats besides carbohydrates has yielded best results. It seems to constitute an ideal food among those tested in respect of all activities inclusive of fecundity and longevity. From an average of about four eggs without any artificial food as high an average as 76·1 eggs per female with a record number of 164 eggs as maximum per female has been obtained on a raisin diet. Results of a few experiments on oviposition responses in relation to oviposition sites such as roots, flower-buds, bolls, etc. are also presented.

Acknowledgements

The authors wish to record their gratitude to the Indian Central Cotton Committee for financing the scheme under which these investigations were made possible. They also beg to tender their grateful thanks to the Cotton Specialist, Coimbatore, for affording facilities for the studies.

REFERENCES

Ballard, E. (1923). *Mem. Dept. Agric. Ind. (Ent. Ser.)* **7**, No. 12

Creighton, J. T. (1938). *J. Econ. Ent.* **19**

Dean, R. W. (1938). *J. Econ. Ent.* **31**, 241

De Jung, J. K. (1938-39). *Treubia* **16**

Dick, J. (1937). *Ann. Appl. Biol.* **24**, 762

Dorman, S. C. *et al.* (1938). *J. Econ. Ent.* **31**, 44

Evans, A. C. (1938). *Ann. Appl. Biol.* **25**, 571

Fletcher, T. B. (1913). '*Some South Indian insects*,' p. 333

Flanders, S. F. (1936). *Ann. Ent. Soc. Amer.* **29**, 259

Kobayashi, H. (1938). *Trans. Nat. Hist. Soc. (Formosa)* **24**

Kozhantshikov, T. W. (1938). *Bull. Ent. Res.* **29**, 103

Larson, A. Q. and Fisher, C. K. (1925). *J. Agric. Res.* **29**, 297

Larchenko, K. (1937). *Lenin Acad. Agric. Sci. (Rev. Appl. Ent.* 1938)

Lefroy, H. M. (1908) '*Indian insect life*,' p. 389

Mackerras, M. (1933). *Bull. Ent. Res.* **24**, 353

Norris, M. J. (1934). *Proc. Zool. Soc. (Lond.)*, p. 333

Paddock, F. B. and Reinland, H. J. (1919). *Texas Agric. Exp. Sta. Bull.* **256**

Ramakrishna Ayyar, T. V. (1918). *Madras Year Book*, p. 1

Sherman, H. C. (1930). '*Chemistry of food nutrition*' : Macmillan & Co.

Uvarov, B. P. (1928). *Trans. Ent. Soc. (Lond.)* **76**, 255

STUDIES ON THE COTTON JASSID (*EMPOASCA DEVASTANS* DISTANT) IN THE PUNJAB

I. VARIETAL SUSCEPTIBILITY AND DEVELOPMENT OF THE PEST ON DIFFERENT VARIETIES OF COTTON

BY

PIARE MOHAN VERMA

AND

MOHAMMAD AFZAL

WITH A STATISTICAL APPENDIX BY MOHAMMAD AFZAL AND DWARKA NATH NANDA

Cotton Research Laboratory, Lyallpur

(Received for publication on 26 May 1939)

INTRODUCTION

JASSIDS are well known all over the world for the severe losses which they cause to a variety of economic crops. A number of species infest cotton. Thus we have *Empoasca facialis* Jac. in French Sudan [Vuillet 1925], Nigeria [Golding, 1928], Southern Rohdesia [Peat, 1928] and Uganda [Hargreaves, 1934]. *Empoasca flavescens* Fabre infests cotton in Philippines [Otanes and Butae, 1935].

In India, Lefroy [1906] mentioned jassids as a serious pest of several new American and Egyptian cottons in Bihar. Burt [1916] noted '*Empoasca gossypii*' (probably *Empaosca devastans* Distant) on some American cottons at Cawnpore. Misra [1919] mentioned *Empoasca notata* Melich as a pest of cotton in North Bihar. Vuillet [1925] stated that *Empoasca devastans* Distant and *Empoasca notata* Melich were the most dangerous of the less-known pests of cotton in British India. *Empoasca devastans* is also a pest of cotton in Madras [Ayyar, 1935]. Jenkins [1936] regards jassids as the most serious pest of cottons in Sind.

Of the species that infest cotton in the Punjab, *Empoasca devastans* Distant is the most serious and the commonest. It may be mentioned at the outset that *desi* cottons are practically immune to the pest and it is only the American varieties that suffer. There are of course marked varietal differences in the latter group as well and susceptibility to jassid attack is usually the chief limiting factor to the general cultivation of otherwise very desirable types. Several new strains of American cottons recently evolved by the Cotton Research Botanist, namely 36F, 38F, 58F and a host of others, although very desirable from the agricultural point of view, are not being pushed into general cultivation on account of their susceptibility to jassids. Records also show that during 1913-14 the failure of 3F cotton, the first variety of American cotton introduced into this province, was due to the ravages of this pest. In fact it is true to say that no variety of American cotton will be a commercial success in the Punjab unless it is resistant to jassids.

So far it has not been possible to control this pest by chemical and mechanical means [Sloan, 1938]. The pest also does not suffer to any great extent from the attack of predacious and parasitic enemies. The only hope, therefore, lies in the discovery of a resistant variety of cotton.

The problem

During 1937 and 1938 work was confined to the investigation of the following two aspects of the problem :

1. The differences in susceptibility to jassid infestation among different important varieties of cotton.
2. The causes of the inability of the insect to infest some varieties.

Comparative jassid population on different varieties of cotton at Lyallpur

Detailed records of the annual prevalence of jassids on different varieties of cotton in the Punjab before 1936 are rather scanty. The only published records in this connection are those of Lal [1937] who mentioned that the resistance of 43F (now called 289F/43) against jassids, though higher than that of some very susceptible varieties such as 38F, 45F and 289F, is not so high as that of 4F and that the resistance of Jubilee cotton though higher than that of the American varieties is about the lowest among the *desis*.

Preliminary observations soon showed that an ideal census of jassids, taking into account all the stages, i.e. eggs, nymphs and adults was practically impossible. The eggs are laid in the leaf-veins and it is impossible to examine and count their number in field samples. The nymphs and adults could be recorded on leaves, but owing to vital differences in their habit, their relative numbers could not be determined by absolutely identical methods.

A survey of literature showed that the commonest method of recording jassid population has been either to collect adults by sweeping and count them or count the living nymphs on a number of leaves. Sweeping method has been severely criticised by Delong [1932]. According to him, samples of insects collected by this method from various situations would vary with the prevailing conditions such as temperature, humidity, wind velocity, position of the operator in relation to the wind, position of the sun and size and condition of the crop. He came to the conclusion that, at best, this method could only give a very rough and an inaccurate estimate of the comparative insect population.

Jassid population was determined in a field at the Cotton Research Botanist's farm at Risalewala (Lyallpur) where the following varieties had been sown in contiguous plots measuring 21 ft. × 171 ft. during 1937 and 1938 :—

289F/43, LSS, 289F/K 25, 4F, 100F and Jubilee cotton.

The plots were sown on 14 May each year and received identical cultural treatments such as irrigation, hoeing, etc. Each variety was replicated seven times according to Fisher's randomized block system. During 1937, observations were recorded in all the plots, but during 1938 only five replications of each variety were taken into consideration. The following methods were tried :

Sweeping

Sweeping was conducted with a hand-net 13 in. in diameter and having a terminal tubular muslin bag 27 in. long and with a wooden handle 27

in. in length. Sixteen forward and sixteen backward semi-circular sweeps, as far as possible, over the same distance were made on the cotton plants in the middle rows of each plot, thus making a total of 224 sweeps for each variety during 1937 and 160 during 1938. Full cognizance was taken of Delong's criticism of this method and the following precautions were taken :

(*i*) As far as weather conditions permitted, the sweepings were done in the morning hours only and the work finished in a reasonably short time.

(*ii*) The direction of the sweeps was always against the wind.

(*iii*) Sweeping on adjacent plots, one after another, was avoided.

(*iv*) The operator and the appliances were the same throughout.

The total number of jassid adults collected in each day's sweepings during 1937 and 1938 are given in Tables I and II.

TABLE I

Jassid adults counted on different varieties of cotton by sweeping, 1937

Date of observation (1937)	Number of jassid adults counted in 224 sweeps of hand-net				
	LSS	4F	289F/43	100F	289F/K25
June 8	..	..	..	..	2
„ 15	..	1	1	1	2
„ 22	..	2	3	4	5
„ 29	3	4	3	4	6
July 5	5	4	4	7	21
„ 12	26	32	33	46	74
„ 19	44	60	57	57	101
„ 26	122	135	144	169	276
Aug. 2	252	276	300	315	560
„ 9	438	480	564	630	927
„ 16	584	742	776	823	1176
„ 27	778	881	946	976	1663
Sept. 4	1087	1260	1186	1320	2281
„ 10	992	1079	1074	1170	1967
„ 17	534	670	718	863	1366
„ 23	345	466	530	589	802
Oct. 1	201	226	309	336	606
„ 8	142	145	200	254	460
„ 15	61	67	79	96	186
„ 22	40	57	59	94	156
„ 31	23	26	34	57	89
Nov. 5	12	10	31	32	59
„ 12	6	11	15	20	28

TABLE II

Jassid adults counted on different varieties of cotton by sweeping, 1938

Date of observation (1938)	Number of jassid adults counted in 160 sweeps of hand-net					
	Jubilee cotton	LSS	4F	289F/43	100F	289F/K25
June 7	..	..	..	..	..	..
„ 15	..	..	..	..	1	..
„ 22	..	..	..	..	..	6
July 1	..	4	..	..	3	12
„ 6	..	..	..	1	2	8
„ 13	4	3	10	8	10	24
„ 21	17	22	20	28	20	78
„ 26	12	8	13	10	19	109
Aug. 3	9	16	13	24	23	149
„ 10	27	30	37	38	55	186
„ 17	32	36	34	43	58	200
„ 23	24	36	28	54	41	201
„ 30	24	38	37	57	46	206
Sept. 5	32	49	44	61	60	235
„ 13	17	29	22	26	29	222
„ 21	4	15	14	13	14	145
„ 28	..	16	11	11	13	101
Oct. 5	6	12	9	8	9	82
„ 12	2	11	4	12	9	52
„ 19	2	14	7	9	16	41
„ 26	..	10	2	13	9	41

COUNTING OF LIVING NYMPHS ON THE LEAVES OF PLANTS IN THE FIELD

Two plants of normal size and growth were selected at random in each plot at each observation and the adults and nymphs carefully counted by

slowly turning over the leaves. Thus during 1937, 14 plants of each variety were examined and 10 in 1938. As most of the adults flew away, the number of nymphs only counted by this method during 1937 and 1938 are presented in Tables III and IV.

TABLE III

Jassid nymphs counted on different varieties of cotton, 1937

Date of observation (1937)	Total jassid nymphs counted					
	No. of plants counted	LSS	4F	289F/43	100F	289F/K25
21 June	14	1	..	1	2	5
28 ,,	,,	1	3	2	2	9
5 July	,,	2	4	4	7	10
12 ,,	,,	19	20	3	21	41
19 ,,	,,	29	46	38	48	60
26 ,,	,,	74	74	92	104	186
3 Aug.	,,	108	151	145	230	427
10 ,,	,,	152	222	221	266	592
17 ,,	,,	194	289	339	300	873
28 ,,	,,	190	221	239	276	622
10 Sept.	,,	156	178	223	253	645
17 ,,	,,	102	160	180	209	479
23 ,,	,,	80	106	106	170	390
1 Oct.	,,	60	83	81	103	280
8 ,,	,,	45	43	82	120	379
14 ,,	,,	24	35	32	33	100
22 ,,	,,	26	27	40	49	112
31 ,,	,,	36	39	43	60	79
5 Nov.	,,	18	21	34	38	45
12 ,,	,,	4	9	2	12	27

TABLE IV

Jassid nymphs counted on different varieties of cotton, 1938

Date of observation (1938)	Jassid nymphs counted						
	No. of plants counted	Jubilee cotton	LSS	4F	289F/43	100F	289F/K25
7 June	20	..	..	..	..	..	..
15 „	20	..	..	..	..	..	1
22 „	12	..	..	1	1	..	5
1 July	15	..	..	1	1	..	2
6 „	20	..	..	..	..	2	19
13 „	10	2	1	3	1	3	29
21 „	20	1	3	2	2	4	52
26 „	10	2	2	..	2	6	102
3 Aug.	10	..	6	3	5	5	124
10 „	10	4	8	3	6	11	90
17 „	10	4	5	12	5	14	88
23 „	10	4	8	14	10	17	140
30 „	10	5	12	16	9	11	156
5 Sept.	10	8	13	16	17	22	162
13 „	10	4	7	7	17	13	108
20 „	10	1	4	4	13	6	82
28 „	10	1	9	6	8	8	61
5 Oct.	10	1	3	1	5	11	46
12 „	10	..	5	4	8	4	56
19 „	10	1	2	2	1	9	38
26 „	10	..	2	2	4	5	26

COUNTING OF ADULTS AND NYMPHS AFTER FUMIGATING THE PLANT

Two normal plants were selected as before in each plot and smartly enclosed in a fumigating chamber. Before enclosing the plants white sheets of paper were spread underneath. The insect life was killed by pumping calcium cyanide gas from the top of the chamber. The dead insects were counted both on the leaves and on the white paper. Shaking the plants was specially avoided. The total number of nymphs and adults counted on plants of different varieties during 1937 and 1938 are presented in Tables V and VI.

TABLE V

Estimation of jassid population on different varieties of cotton at Lyallpur by fumigation, 1937

Date of observation (1937)	No. of jassid adults and nymphs counted on 14 plants				
	LSS	4F	289F/43	100F	289F/K25
8 June	..	2	..	..	2
16 ,,	..	2	1	2	5
23 ,,	4	4	4	3	12
30 ,,	4	5	7	7	18
6 July	16	10	12	13	40
13 ,,	27	44	44	47	92
20 ,,	54	57	59	77	130
27 ,,	138	141	137	174	276
4 Aug.	178	199	214	319	605
11 ,,	237	278	279	334	739
18 ,,	280	346	381	303	1082
28 ,,	319	369	383	476	1156
4 Sept.	419	477	511	590	1169
11 ,,	283	316	421	458	945
18 ,,	200	261	265	365	659
24 ,,	125	143	191	292	429
2 Oct.	80	117	174	171	400
9 ,,	91	84	87	140	329
15 ,,	71	72	66	105	189
23 ,,	63	73	86	90	170
30 ,,	42	56	84	87	131
6 Nov.	13	18	21	46	67
13 ,,	11	12	9	13	20

TABLE VI

Estimation of jassid population in different varieties of cotton at Lyallpur by fumigation, 1938

Date of observation (1938)	No. of jassid adults and nymphs counted on 10 plants					
	Jubilee cotton	LSS	4F	289F/43	100F	289F/K25
15 July	3	5	8	6	7	46
23 ,,	4	5	5	7	6	76
28 ,,	4	3	2	5	10	109
4 Aug.	1	14	7	10	9	133
12 ,,	3	13	6	8	10	103
19 ,,	7	9	17	12	12	130
25 ,,	7	23	17	14	18	174
1 Sept.	9	26	23	19	21	203
7 ,,	6	21	20	20	45	207
16 ,,	4	9	11	15	15	131
24 ,,	2	3	12	9	10	95
30 ,,	1	3	1	3	4	76
7 Oct.	1	2	3	4	4	56
14 ,,	1	5	2	8	12	46
21 ,,	..	5	7	7	11	41
28 ,,	..	5	8	4	8	28

A detailed statistical examination of these tables has been made and very interesting conclusions have been arrived at. The comparison of different varieties, so far as resistance or susceptibility to this pest is concerned is, therefore, not dealt with here, but will be found in the appendix.

A comparison of the figures obtained in the two years shows that the incidence of attack was much higher in 1937 than in 1938. While comparing the tables of any one method it has to be kept in view that although different units—for example number of sweeps or the number of plants—had been employed, yet even after accounting for this, the incidence would be see to be much higher in the former year.

The data also show that the maximum prevalence periods of jassids were fairly constant in time, in both the years ; the highest infestation was noticed from the end of August to the second week of September.

The efficiency of the various methods tried will be dealt with in the appendix. A few general observations are, however, given here.

Sweeping was found to be very satisfactory for adults. Our work is not open to the objections raised by Delong [1932], as the various plots in which population was recorded were contiguous and all the operations were conducted in an identical manner in a reasonably short time on the same day. The factors that affected one plot also affected all the others to practically the same extent. Sweepings of any one day were, therefore, quite comparable.

Counting the insects in living condition on the plants was found to be good for nymphs but not for adults which invariably flew away. In this case it is essential that the operation should be conducted very calmly without shaking the plants too much as older nymphs also have a tendency to hop off, if disturbed. This method, however, depends too much on human factor.

Fumigation is a fairly reliable method both for adults as well as for nymphs. Lal [1938] regards this method satisfactory for adults but not for nymphs. Our method of working differed from his in that we counted the insects on the foliage and avoided too much shaking of plants. This was done because even after vigorous shaking quite a large number of insects remained sticking on to the plant parts. On the whole we found it more satisfactory to count the insects *in situ* rather than to try to collect them on the paper spread below the plant. Moreover, if shaking is resorted to, there is always a possibility of a number of smaller nymphs being blown off the paper where they cannot be distinguished from dust particles. We fully agree with Lal [1938] in the view that ' jassid attack is not uniform in the cotton fields' and ' the accuracy of population estimation of this insect should depend on a large number of samples drawn from all parts of the fields '.

Development of jassids on different varieties of cotton

Developmental studies were carried out on both *desi* and American varieties. Amongst the latter, both resistant and highly susceptible varieties were included. The aim in view was to find out the differences, if any, in the behaviour of the insect on different types of hosts. The following experiments were performed :

To determine the percentage of development of Empoaca devastans *nymphs to adult stage on different varieties of cotton*

Equal number of 1st instar nymphs collected from *bhindi* (*Hibiscus esculentus*) plants were caged on the following varieties seven times during 1937 and four times during 1938 :

Jubilee cotton
39 Mollisoni
LSS
4F
289F/43 and
38F

Of these, the first two are *desi* varieties and most resistant while 38F is the most susceptible of all the American strains. The rest are fairly resistant. At

each observation three plants of the same age of each variety growing in pots were selected and covered separately with wire-gauze jassid-proof cages. The leaf-area offered for each variety was kept approximately the same. The nymphs were handled with a camel-hair brush and unless a nymph moved off after liberation it was not considered healthy and was rejected. The number of these developing into adults was determined daily. Table VII gives a summary of the results.

TABLE VII

Nymphal development on different varieties of cotton

Variety	Total nymphs liberated		Total adults emerged		Percentage of success	
	1937	1938	1937	1938	1937	1938
LSS	900	315	691	274	76·7	86·9
4F	900	315	719	272	79·8	86·9
289F/43	900	315	723	262	80·0	83·1
38F	900	240	732	202	81·3	84·1
289F/K25	..	315	..	272	..	86·9
39 Mollisoni	900	315	700	209	77·3	66·3
Jubilee cotton	900	315	698	254	77·5	80·6

The above experiments showed that the nymphs of *E. devastans* can flourish equally well on all cottons, susceptible or resistant. This work confirms some previous observations on the subject by Husain [1937] who experimented with different varieties. Peat [1926-27], working on *E. facialis*, is also of the view that jassid nymphs if forced to remain on plants of Cambodia cotton, a highly resistant strain, can live and cause symptoms of attack on plants that are practically immune in the field.

To determine the comparative number of eggs laid on desi *and American varieties of cotton by equal number of* Empoasca devastans *females*

During 1937, equal number jassid females that had not oviposited before were confined on leaves of plants of all the varieties mentioned above. These plants were growing in pots and were sown on the same date. The insects were allowed to oviposit on one leaf for 24 hours, after which fresh leaves were provided. This was continued as long as even one jassid female survived. The total number of eggs laid by each set of females was determined by removing the leaves that had been oviposited upon each day and dissecting the leaf veins carefully under a high power binocular. The results are summarised in Table VIII.

TABLE VIII

Number of eggs laid on different varieties of cotton in 1937

No. of jassid females	Period of experiment	Eggs laid on different varieties					
		LSS	4F	289F/43	38F	39 Mollisoni	Jubilee cotton
5	9 to 20 July	33	26	35	45	6	8
5	13 to 26 July	25	34	33	42	11	6
5	21 July to 6 Aug.	32	36	39	47	5	6
5	4 to 21Aug.	44	45	53	57	9	14
5	7 to 27 Sept.	50	54	31	54	9	12
5	1 to 23 Oct.	32	37	27	55	8	10
5	9 Nov. to 11 Dec.	16	15	17	15	1	2

The comparative number of eggs laid on different varieties of cotton were tested yet in another manner. Three plants of each variety sown on the same date in separate pots were selected. An attempt was made to select an equal quantity of leaf material for each variety. The plants were covered with jassid-proof wire-gauze cages and equal number of jassid males and females caught from *bhindi* (*Hibiscus esculentus*) plants were liberated on each plant. The nymphs hatching out each day from each plant were counted. The results are given in Table IX.

TABLE IX

Comparative number of jassid nymphs hatching on different varieties of cotton during 1937

Duration of experiment	Total females liberated	Jassid nymphs hatched on different varieties					
		LSS	4F	289F/43	38F	39 Mollisoni	Jubilee cotton
5 to 28 July	60	69	96	94	101	20	23
2 to 30 Aug.	60	92	90	91	81	17	22
5 Sept. to 2 Oct.	60	112	131	95	134	28	31
7 Oct. to 8 Nov.	60	61	55	69	92	15	15
13 Nov. to 20 Dec.	45	35	46	47	53	10	9

In the above experiment it is possible that many of the females may have oviposited before, but the results could not be vitiated by this fact as this factor was the same for all the varieties. The object of the experiment was only to compare the relative ability of the females to oviposit on *desi* and American strains. It cannot be believed that the fact that fewer eggs were always laid on the former was due to the females having oviposited before. Evidently the factor responsible for this lay more in the plants rather than in the insect.

During 1938, a suspicion arose that although the females may sometimes oviposit freely on the *desi* strains, yet some of the eggs may not hatch. To test this, the hatching percentage of eggs on different varieties of cotton and on *Hibiscus esculentus* which is the most favoured host of this insect in the Punjab was determined in the following manner.

Equal number of jassid females, as before, were liberated on leaves of different varieties of cotton and *bhindi* as in 1937 and the number of nymphs hatching out from these was determined. The unhatched eggs were counted by dissecting the leaf-veins after the nymphs had ceased to emerge. The egg shells shrivelled up and became transparent after hatching and could not be distinguished from the leaf-tissues but an unhatched egg could be made out for sometime owing to the presence of yolk in it. The results obtained are summarised in Table X.

TABLE X

Hatching percentage of jassid eggs laid on different varieties of cotton and bhindi *in 1938*

Host plant	No. of females used	Total eggs laid	Total nymphs hatched out	Hatching percentage
39 Mollisoni	40	33	33	100
Jubilee cotton	40	47	47	100
289F/K25	40	290	286	98·6
38F	40	265	263	99·2
4F	25	154	150	94·3
289F/43	30	157	153	97·4
LSS	35	180	174	96·6
Bhindi	40	503	495	98·4

The following conclusions can be drawn from the experiments described above :

(1) There is a marked reduction in the number of eggs laid by the jassid females on *desi* cottons.

(2) Jassid eggs even when laid in the leaf-veins of immune varieties (*desi*) have no difficulty in hatching.

(3) That the number of eggs laid by jassid females vary with the host-plant. The oviposition is more free on *bhindi* than on cotton plants. This may partly explain the reason for the very severe jassid infestation on this plant throughout the season.

Our results confirm previous observations on the subject [Husain, 1937; Lal, 1937]. Sloan [1938] is also of the view that 'resistance is partly due to the unsuitability of the plant for jassid breeding and partly to its ability to tolerate the pest'.

It is now abundantly clear that causes of resistance or susceptibility of varieties of cotton to this pest must be sought in the leaf-veins [Lal, 1937]. Further work is now being directed to the solution of this problem.

Summary

Jassids are a very serious pest of American cottons in the Punjab. *Desi* cottons are, however, practically immune to it. The species of jassids most prevalent is *Empoasca devastans* Distant.

The first problem tackled was to devise a reliable and quick method for estimating the comparative infestation on different varieties. It has been shown that sweeping with hand-net answers this purpose quite well.

Varietal differences were observed in the case of American cottons. Of the commercially important varieties, LSS was found to be most resistant and 289F/K25 most susceptible. Other varieties, namely 4F and 289F/43, came in between these two extremes in the order mentioned here.

It has been shown that the chief difference between the comparatively resistant or susceptible varieties lay in the number of eggs laid in the leaf-veins of these strains. The eggs when once laid had, however, no difficulty in hatching and the nymphs of all stages also could feed and reach normal maturity on all cottons equally well.

Acknowledgments

The Indian Central Cotton Committee, Bombay, provided funds for the present investigation. Their generosity is gratefully acknowledged.

Our thanks are also due to Mr. Manzoor Abbas for his kindly reading the manuscript and for several suggestions.

REFERENCES

Ayyar, V. Ramanatha (1934). *Madras Agric. Stn. Repts.*, 1934

Burt, B. C. (1918). *Report on the Cawnpore Agr. Station in the United Provinces for the year ending 30th June, 1916*

Delong, D. M. (1932). *Ann. Ent. Soc. Amer.* **25**, 13

Golding, F. D. (1928). *7th Ann. Bull. Agric. Dept. Nigeria*

Hergreaves, H. (1932). *Ann. Rept. Dept. Agric. Uganda*, 1931

Husain, M. A. (1937). *First Conference of Scientific Research Workers on Cotton in India : I. C. C. C. (Bombay) Paper No. 3*

Jenkins, W. J. (1936). *Emp. Cott. Grow. Rev.* **13**, 266

Lal, K. B (1937). *Cur. Sci.* **6**, 88

———— (1938). *Proc. 25th Ind. Sci. Cong.* **3**, 191

Lefroy, H. M. (1906). *'Indian insect pests'*, p. 108

Misra, C. S. (1919). *Rept. Proc. 3rd. Ent. Meeting Pusa*, p. 547

Otanes, F. Q. and Butae, F. L. (1935). *Philip. J. Agric.* **6**, 147

Peat J. E., (1927). *Emp. Cott. Grow. Corp. Reps. Expt. Stn. 1926-27*, p. 105

Sloan, W. J. S. (1938). *Queensland Agric. J.* **50**, 450

Treloar, Alan E. (1935). *'An outline of biometric analysis'*, Pt. II, p. 4 ; Burgeis Publishing Co., U. S. A.

Vuillet, J. (1924). *Rev. Bot. Appl. E. Agric. (Colon)*, **4**, *Bull. 39*

APPENDIX

An accurate method of insect census is one of the most desirable and at the same time a very difficult matter in economic entomology. During the course of the present work emphasis was laid on this aspect of the problem and the three methods mentioned in the text were employed on a large number of varieties for two seasons. The data are presented in Tables I—VI in the text. A detailed statistical examination of these data has been made.

Since the infestation of jassids on different varieties showed a high correlation the significance of the mean difference between any two was found by the help of equation (i) where the standard error of the mean difference was calculated by equation (ii).

$$\text{(i)}\quad t=\frac{(\bar{y}-\bar{x})}{SE_{(\bar{y}-\bar{x})}}$$

$$\text{(ii)}\quad SE_{(\bar{x}-\bar{y})}=\sqrt{SE^2_{\bar{x}}+SE^2_{\bar{y}}-2r_{xy}\,.\,SE_{\bar{x}}\,.\,SE_{\bar{y}}}$$

where $\bar{x}$ and $\bar{y}$ represent the mean infestation on any two varieties and r_{xy} is the coefficient of correlation between the two [Treloar, 1935].

The average seasonal infestation on different varieties is given in Table XI.

TABLE XI

Average seasonal infestation of jassids on different varieties

Varieties	1937			1938		
	Sweeping	Counting	Fumigation	Sweeping	Counting	Fumigation
Jubilee cotton	...	...	...	10·60± 2·60	1·90 ±0·50	3·31±0·69
LSS	247·6±69·5	66·05±14·29	126·43±25·74	17·45± 3·23	4·50± 0·89	9·44± 1·94
4F	288·4±80·0	86·55±19·46	146·76±30·00	15·25± 3·14	4·85± 1·19	9·31± 1·70
289F/43	307·7±80·2	95·35±21·90	162·62±33·10	20·80± 4·44	5·75± 1·18	9·44± 1·31
100F	341·9±87·5	115·15±23·43	195·71±37·50	21·85± 4·40	7·55± 1·33	12·63±2·45
289F/K25	557·1±144·0	268·05±59·29	412·29±85·04	104·90±18·27	69·35±11·35	103·38±14·14

It will be seen from this table that the varieties Jubilee cotton, LSS, 4F, 289F/43, 100F and 289F/K 25 were placed in an ascending order, Jubilee cotton (a *desi* strain) being the least susceptible. Amongst the American strains LSS was found to be very resistant and 289F/K25 highly susceptible.

In order to find out whether the differences between the different varieties were significant or not, the values of '*t*' were calculated and are given in Table XII.

TABLE XII

Values of 't'

Varieties compared	1937			1938		
	Sweeping	Counting	Fumigation	Sweeping	Counting	Fumigation
Jubilee cotton vs. LSS	...	...	...	5·04**	4·48**	4·06**
Jubilee cotton vs. 4F	...	...	...	4·84**	3·60**	4·88**
Jubilee cotton vs. 289F/43	...	...	...	4·49**	4·14**	6·81**
Jubilee cotton vs. 100F	...	...	...	5·59**	6·14**	4·33**
Jubilee cotton vs. 289F/K25	...	...	...	5·86**	6·15**	7·37**
LSS vs. 4F	3·40**	3·33**	3·99**	2·15*	0·53	0·07
LSS vs. 289F/43	2·06	3·49**	3·94**	2·11*	1·69	0·00
LSS vs. 100F	4·41**	4·91**	4·91**	2·49*	3·72**	1·42
LSS vs. 289F/K25	4·11**	4·42**	4·75**	5·70**	6·11**	7·47**
4F vs. 289F/43	2·68*	2·02	2·74*	3·07**	0·95	0·16
4F vs. 100F	4·73**	4·46**	4·28**	4·28**	3·33**	1·93
4F vs. 289F/K25	4·13**	4·36**	4·76**	5·79**	6·17**	7·34**
289F/43 vs. 100F	3·80**	3·39**	3·61**	0·64	1·92	1·57
289F/43 vs. 289F/K25	3·80**	4·53**	4·72**	5·78**	6·04**	5·09**
100F vs. 289F/K25	3·73**	4·15**	4·28**	5·73**	5·98**	7·30**

*denotes significance up to 5 percent level.
**denotes significance up to 1 per cent level.

Some of the interesting features which are brought forth from Table XII are given below.

Comparison of different varieties

It will first be recalled that the degree of infestation during 1937 was much higher than in 1938. No suitable explanation exists for this phenomenon, except possibly the dryness of the atmosphere during the latter year. Our knowledge of the bionomics of this pest is very meagre and, therefore, the causes of the differences in the infestation in different years is at present a matter of conjecture. It is, however, hoped that the work now in progress will throw some light on this phenomenon.

It will be seen from Table XII that Jubilee cotton (a new type of *desi* cotton with lint approximating to American 4F) is the least susceptible type

of all cottons. LSS appears to be the most resistant American variety with 4F next in order. The difference in the susceptibility of 4F and 289F/43 is doubtful while the latter variety appears to be somewhat better than 100F and 289F/K25. In its own place 100F is better than 289F/K25 which is definitely the most susceptible variety under the soil and climatic conditions obtaining at Lyallpur.

Comparison of the three methods

It is quite clear from Table XII that the level of significance of practically all the varieties is the same by the three methods. There are of course slight discrepancies here and there, but these are not such as to cast grave doubts on the similarity of the three methods. This finding is very interesting as now we can employ any one of these methods instead of all the three, and thus save great deal of time and labour. As the counting of living nymphs and fumigation are very time-consuming operations these can be discarded in favour of sweeping. By this method alone the comparative infestation of the different varieties can be accurately determined.

It can also be seen that in years of high infestation, like 1937, the differences between the varieties are brought out much more clearly than in years of low infestation. This is of course to be expected as the experimental error will proportionately be higher when the number of insects dealt with is small.

STUDIES ON *SCHISTOCERCA GREGARIA* FORSK.

*X. ROLE OF WATER IN THE BIONOMICS OF THE DESERT LOCUST

BY

M. AFZAL HUSAIN, M.A. (CANTAB.), I.A.S.

Vice-Chancellor, Punjab University, Lahore†

TASKHIR AHMAD, PH. D. (CANTAB.)

Assistant Entomologist

AND

C. B. MATHUR, M.Sc. (LUCK.)

Locust Assistant, Imperial Agricultural Research Institute, New Delhi

(Received for publication on 20 March 1940)

I. INTRODUCTION

OF the physical environmental factors, temperature and moisture have decidedly the most potent influence on the life-activities of all insects, and for denizens of arid regions, such as the desert locust, moisture is undoubtedly of fundamental importance.

Schistocerca gregaria normally gets its supply of water through food, but when this supply is insufficient and loss of moisture from its body is excessive, the locust will gnaw up any wet substance, even moist wool, though of little nutritive value and thus appease its craving for water [Husain and Mathur, 1936]. According to Buxton [1924], during periods of drought, desert insects obtain the necessary amount of moisture by feeding on 'apparently dry' fragments of plants, as the latter contain a fair amount of moisture absorbed from the saturated, or almost saturated, atmosphere of the cool desert nights. Swarms of locust, after long marches, have been observed to drink water as such [Nikolsky, 1925].

The mass multiplication of locusts, and the consequent development of the so-called 'gregarious' phase, is certainly connected with precipitation. Myriads of hopper bands cannot come into existence in the absence of an abundance of vegetation. Precipitation brings about the conditions of soil-moisture and atmospheric humidity necessary for the luxuriant growth of desert vegetation, which must always precede the mass multiplication of *Schistocerca gregaria* [Husain, 1929] in their permanent home. Ballard and his co-workers [1932] observed this during the last desert locust invasion. They state, 'In most years there is insufficient moisture and food in Sinai (Egypt), to support large swarms of hoppers. The peculiar feature of the present year (1929-30) was the very abundant winter and spring rainfall all over Sinai'.

---

* For previous parts see *Ind. J. Agric. Sci.*, 1933, 1936 and 1937.

† This investigation was conducted at the Locust Research Laboratory, Punjab Agricultural College, Lyallpur.

From his locust survey work in the permanent breeding grounds of *Schistocerca gregaria* in North India, Rao [1929] came to the conclusion that the essential conditions or the breeding and multiplication of locusts and the origination of new locust cycles appeared to be widespread and heavy rain in Iran and Baluchistan in winter followed by heavy and well-distributed rainfall during the monsoon period in the deserts of Sind and Rajputana.

From Bodenheimer's observations [1929] on the life-duration of the starving individuals of *Schistocerca gregaria* at several relative humidities, Uvarov [1931] arrived at the conclusion that higher humidities were favourable for the hopper stages. Hamilton [1936] showed in three species of locusts (*Locusta migratoria migratorioides*, *Schistocerca gregaria* and *Nomadacris septemfasciata*) that atmospheric humidity controlled almost all the life processes. He found that the rate of development of hoppers decreased when atmospheric humidity fell below the optimum, that the adults did not attain sexual maturity when atmospheric humidity was low and that unfavourable humidity adversely affected the fecundity of females. Further, it has been observed that the eggs of *Schistocerca gregaria* are not laid in dry soil and do not develop in a partially saturated atmosphere [Bodenheimer, 1929]. Thus, it would appear that practically every stage in the life-cycle of a locust is greatly influenced by moisture.

For experiments of the nature described in this paper abundant and easily available locust material is essential and such material can be procured only during a locust invasion. Although we are conscious of the incompleteness of the data presented, the possibilities of an approaching cycle of locust activities providing facilities for future work have prompted us to present the results obtained so far.

The investigation which forms the subject-matter of this paper was carried out under the Locust Research Scheme, financed by the Imperial Council of Agricultural Research, India. The Council's generosity is gratefully acknowledged.

II. Method employed and difficulties of procedure

Investigations concerning the influence of environmental moisture on the active stages of such insects, as feed on green leaves, are fraught with several serious handicaps. The presence in a small cage of green leaves which constantly transpire and of hoppers and adults, which give out from their bodies, along with expired air and faecal matter, a considerable amount of water, are factors which disturb the relative humidity persistently. This can be avoided to a certain extent by maintaining a current of air of the required relative humidity, but in cases where air currents of low humidity are used, the leaves dry up so quickly that without frequent replacements the insects are likely to remain underfed and the results vitiated. It will thus be observed that a constant disturbance of relative humidity and an underfeeding resulting from a quick drying up of food material under conditions of low humidity are two sources of error which develop in inverse proportion : adjust the one and the other develops.

In trying to maintain low humidity within reasonable range, Hamilton [1936] supplied food to his experimental locusts only once a day. In several cases, he even 'partially ' dried the leaves before presenting them to his insects.

He does not make any mention of the quantity of food eaten. As has been stated above, under such conditions the danger of underfeeding is evident. In Hamilton's experiments the death rate was very high. It must not be forgotten that the moisture content of the body of an insect is not solely dependent on atmospheric humidity, and that the physiological changes resulting from a deficiency of food and particularly of its water-content are liable to be confused with those arising directly from the effect of the dryness of the surrounding air.

Even in the case of eggs, there is considerable difficulty. On the one hand the eggs of the desert locust require an almost saturated atmosphere and a relatively high temperature for their development ; on the other hand, they are extremely susceptible to fungus and nematode attacks. High temperature and high humidity are exactly the conditions which are favourable for a vigorous growth of fungi and a quick multiplication of nematodes, and therefore it is often an extremely difficult matter to ensure successful hatching.

Water, soil and apparatus used in such experiments can be sterilised, but it is not as easy to deal with the eggs in a satisfactory manner. They are very delicate and fungicides are positively harmful to them. All that one can attempt to do is to wash the eggs thoroughly in sterilised distilled water. This method is however, not always an effective one ; even a few stray spores present may develop quickly under conditions of warmth and humidity and destroy the eggs. On account of these handicaps we have had numerous failures and a very large number of experiments had to be conducted to obtain the data presented in this paper.

III. Influence of atmospheric humidity on sexual maturation and longevity of adults

Sexual maturation

Temperature has a well-defined influence on the maturation of the sex-glands. For example, the pre-oviposition period of *Schistocerca gregaria* adults exposed to 36°C. is about three weeks and at 40°C. this period is reduced to about two weeks [Husain and Ahmad, 1936]. The relative humidity of the atmosphere has also been regarded as a factor influencing sexual maturation. Roubaud [1930] observed that *Schistocerca gregaria* adults kept in a moist atmosphere reached sexual maturity after three to four weeks only. On the other hand, sexual maturity was completely inhibited in adults placed in a dry atmosphere. At 35-40 per cent relative humidity and at temperature of 30°-40°C. the adults in his experiments lived for over ten months without ovipositing. He states :—

' J 'indiquerai tout d'abord qu'en captivite, les criquets maintenus en air humide (au moins a' 50 pour 100 d' etat hygrometrique) et a la chaleur peuvent parvenir rapidement et sans arret a la reproduction.....D' autre part, si l 'on soumet des criquets parvenus a l' etate adulte, mais encore sexuellement immatures, a des conditions de secheresse continue, plus ou moins comparable a celles des regions desertiques, on les voit supporter parfaitement bien ces influence.....Les criquets maintenus en permanence a une haute temperature continue (30°C.—40°C.) mais avec un etat hygrometrique artificiellement abaisse a 35-40 pour 100, passent a une condition de latence tres caracteristique ; leur pigmentation n'evolus pas, l'activite alimentair, d' abord tres grande, se relentit lentement, tandis que l' evolution sexuelle se montre completement suspendue dans les deux sexes ; les insectes peuvent ainsi etre conserves pendant des mois en anhydrobiose sans parvenir a la maturite sexuelle. '

He thus concludes that sexual development is arrested by low atmospheric humidity. Unfortunately he does not mention anything about the food of the insects under experiments. Did he provide green leaves ? If so, were not the locusts able to get the required amount of moisture from their food ? In an atmosphere, where relative humidity is low, it is almost certain that the green leaves supplied as food would dry up very quickly. It seems, therefore, highly probable that in such experiments drying up of the food and the consequent underfeeding, resulting in deficiency of water in the tissues of the insect, are significant factors in inhibiting sexual maturation ; dryness of the air may perhaps be an indirect factor. Further it must be recognised that sexual maturity and oviposition are two distinct and independently controlled processes.

The latest contribution on the relation of atmospheric humidity to sexual maturity among locusts is that of Hamilton [1936]. He experimented with three species of locusts and arrived at the conclusion that in all these species, sexual maturity was retarded in the adults living in an atmosphere which contained either very low or very high relative humidity. Thus he found that for *Schistocerca gregaria* the lowest relative humidity at which sexual maturation occurred was 40 per cent at 90°F. and 45 per cent at 100°F. and that the optimum range of humidity was 40-75 per cent. Humidity of 80 per cent was considered by him to be the upper limit for sexual maturity. As has been shown above, it is doubtful if Hamilton was able to keep his insects properly fed and retardation in sexual development may have been the result of underfeeding. In the following account it is shown that when an adult desert locust is properly fed and gets the optimum amount of water through its food, the atmospheric humidity has no noticeable effect on the maturation process. All that matters is the presence of the requisite amount of moisture in the body, no matter how it is obtained and retained.

In one of our experiments, two pairs of fliers, obtained from hoppers bred under similar environmental conditions, were kept from the date of acquiring wings (20-21 March 1934) at 30°C. in 85 and 35 per cent relative humidity respectively. Fresh cabbage leaves were supplied four times daily. The female at 85 per cent relative humidity dropped the first batch of eggs on 6th April, i.e. after 17 days ; the female at 35 per cent relative humidity oviposited on 15th April, i.e. after 26 days. Thus sexual maturation was not inhibited but only delayed slightly by low atmospheric humidity.

In another experiment two lots of freshly hatched hoppers were bred crowded at 35°C. in 85 and 35 per cent relative humidities. On acquiring wings they were provided with moist sandy soil for oviposition, which was, however, covered over with thin parchment paper, and a layer of dry soil half an inch in thickness. Thus the moisture in the soil below could not disturb the relative humidity of the air above. The locusts were fed four times every day, as in the previous experiment. In 85 per cent relative humidity, a pair which had acquired wings on 9th September 1935, copulated and the female laid eggs on 24th September. Another pair, which was bred in 35 per cent relative humidity and which had acquired wings on 11th September copulated on 25th September. The female bored twice for oviposition on the same date. Finding the soil unsuitable for oviposition the eggs were withheld for six days and then dropped on the surface of the soil on 1st October. Thus the

preoviposition period was 15 days in the former case, and 14 days in the latter case, i.e., the adults in low and high humidities attained sexual maturity simultaneously.

It would appear from these experiments that in low atmospheric humidity sexual maturation of the desert locust is not significantly slackened and certainly not inhibited. We, therefore, believe that if the adults are provided with an ample supply of fresh food, e.g. if fed on green succulent leaves (preferably on a plant), the desert locust can attain sexual maturity however deficient in moisture the atmosphere may be.

Longevity of adults

To study the influence of saturated and moisture-deficient atmosphere on the longevity of freshly emerged adults the following experiment was conducted :

Two similar wire-gauze cages with moist soil at the bottom, were set up side by side. Along the four sides of one of the cages were hung curtains of cotton lint which were soaked with water and the lower free margins of which were kept immersed in a channel full of water. Thus the four sides of the cage were maintained moist. The water lost through evaporation from the surface of the cotton lint was replenished from the water provided in the channel. The top of the cage was left uncovered. In this manner the humidity in this cage was maintained at almost the saturation point. The other cage was left at room humidity which averaged 40 per cent. The longevity of the adults kept in these two cages is shown in Table I. All the adults were of the same age and were bred together before their transfer to their new environment.

TABLE I

Longevity of Schistocerca gregaria *adults in saturated and partially saturated atmospheres (temperature range : 26·6 to 36·6°C.)*

Serial No.	Date of transfer to cage	Saturated atmosphere (relative humidity—100 per cent)		Partially saturated atmosphere (average relative humidity 40 per cent)	
		Date of death	Longevity (days)	Date of death	Longevity (days)
1	15 July	17 July	2	30 July	15
2	,,	20 ,,	5	2 August	18
3	,,	21 ,,	6	28 ,,	44
4	,,	22 ,,	7	12 Sept.	59
5	,,	22 ,,	7	12 ,,	59
6	,,	30 ,,	15	23 ,,	70
7	17 July .	30 ,,	13	..	..
8	20 July .	5 August	16	..	..

It will be seen that the adult that lived longest in saturated atmosphere survived for 16 days only. Many of them lived for a much shorter period. On the other hand, in the cage kept at room humidity (average 40 per cent) the longevity reached a maximum of 70 days. Thus in an atmosphere containing moisture to saturation point the life-span of *Schistocerca gregaria* is cut short and the mortality percentage increases. It may be mentioned in this connection that the desert locust is extremely susceptible to bacterial and fungal diseases, and possibly this is one of the chief factors responsible for the short life of the locust in a saturated atmosphere. Roubaud [1933] also observed high mortality in humid atmosphere and very few deaths and longer life in dry atmosphere.

Hamilton [1936] found a gradual decrease in the length of life of *Schistocerca gregaria* with a rise in humidity. Eighty per cent humidity and above were found to be detrimental to the desert locust. These observations lead one to the conclusion that a comparatively less humid atmosphere suits the desert locust better, provided it is able to get the requisite water supply from its food. This is exactly the condition in the natural home of the desert locust. This view finds further support from the fact that the gregarious-phase locust flies far and wide into fertile areas but cannot survive and multiply for more than a generation or two in areas where humidity is higher than in its desert home. Thus while the fliers may reach the extreme eastern limits of India, their permanent home does not extend to the east and north beyond the Rajputana desert.

IV. Soil moisture and oviposition

Under natural conditions swarms of the adult locust oviposit in a great variety of soils, the one necessary condition being suitable soil moisture. In soils where moisture is deeper than usual eggs are laid at a comparatively greater depth than in soils where moisture is nearer the surface.

In a particular instance at Tala-gang (Attock district, Punjab) it was noticed that a swarm of the desert locust which was ready to lay eggs, settled on the sloping sandy bank of a stream of water. The soil moisture of the bank varied from saturation point, near the water edge of the stream, to almost dry sand at the top of the bank. The locust swarm restricted its egg-laying activity to a longitudinal strip of land a few feet broad and running parallel to the stream. For oviposition the soil next to the stream which was full of water, as well as the dry or almost dry soil farthest from the running water was avoided. In this connection, Gough [1916] states, ' The females appear to be very careful in the selection of the best site in the neighbourhood for depositing their eggs ; and yet the choice varies immensely in different places. Absolutely dry sand and wet mud are never used if more suitable positions are available. Banks of canals and drains or irrigation channels in the fields are often selected. In such places the eggs are in a definite zone, not too close to the water (at the time of laying) nor too high above it, as to cause the place to be too dry '.

Our experience in the laboratory confirms these observations. Fully mature females placed in cages provided with dry sandy soil bored at several places but did not oviposit. They withheld their eggs as long as was physically

possible for them to do so and finally dropped the eggs on the surface of the soil. Where soil was watered at this stage the eggs were readily laid in the soil in the normal manner.

Definite experiments were conducted to analyse this behaviour. An oviposition cage was fitted with glass tubes (3 cm. bore and 15 cm. long) which were filled with dry and moist sand up to different depths and in different orders. In order to prevent moisture of the wet soil running into the dry soil, the two layers were separated by thin water-proof paper. Mature females were introduced in these cages. The results are presented in Table II.

TABLE II

Influence of soil-moisture on oviposition

Upper layer of soil		Lower layer of soil		Total depth of bore in which eggs were laid (cm.)	Remarks
Nature	Depth (cm.)	Naure	Depth (cm.)		
Moist	7·5	Dry	7·5	8·0	Eggs laid
,,	8·0	,,	7·0	8·0	,, ,,
,,	6·5	,,	8·5	6·5	,, ,,
,,	5·5	,,	9·5	..	No eggs laid; bored into dry soil
,,	5·0	,,	10·0	..	,, ,,
,,	4·0	,,	11·0	..	,, ,,
,,	3·5	,,	11·5	..	,, ,,
,,	2·0	,,	13·0	..	,, ,,
Dry	9·5	Moist	5·5	8·0	Eggs laid
,,	9·0	,,	6·0	9·5	,, ,,
,,	8·0	,,	7·0	9·8	,, ,,
,,	8·0	,,	7·0	8·5	,, ,,
,,	4·0	,,	11·0	7·5	,, ,,
,,	3·0	,,	12·0	7·0	,, ,,
,,	2·0	,,	13·0	6·8	,, ,,

It will be noticed that when the layer of moist soil which is always sought for oviposition, lay below the dry soil the females bored through the dry layer, if it was not too deep, pierced the paper and getting into the moist soil oviposited there. On the other hand, when the top layer was moist, the female, in order to avoid the dry soil below, laid eggs at a much shorter depth than normal. When the top layer of moist soil was much too thin the eggs were not laid there, it being physically impossible for the locust to lay eggs at a depth shorter than a certain minimum. Normally the abdomen is thrust into soil up to the III segment or so before the eggs are deposited. When the top layer is of dry soil and is too deep for the abdomen of the female to bore through, she desists from oviposition.

It has been commonly observed that swarms of locust do not settle and lay eggs in a field if it is flooded with water. What is it that prevents the locust from doing so ? In an experiment ripe females were kept in a cage in which water was kept standing. They did not lay eggs as long as the water was there, but when the surface water was drained off the eggs were laid in the otherwise waterlogged soil. In another experiment females were made to oviposit in water. A breeding cage was fitted with test-tubes, each of which was filled with water except for the upper two inches which contained soil supported by waterproof paper partition which was fixed to the tube by means of wax. The female bored through the two inches of sand and pushed her abdomen into the water and dropped eggs and deposited froth. This shows that a female is not incapable of laying eggs in water but in a flooded field she cannot do so because perhaps the conditions there do not allow her to get the requisite anchorage to bore a hole. It must be made clear that in these experiments the locusts were made to lay eggs in somewhat unfavourable situations.

While making observations on the above-mentioned female as she laid eggs in water, it was interesting to note her rather extraordinary behaviour. Normally, as a female oviposits she contracts her abdomen a little to allow the egg to be deposited. The female which was ovipositing in water had no such necessity. Each egg that was deposited dropped down at the bottom. Thus the female continued to lay the cluster without contracting her expanded abdomen. Finally, the female started withdrawing her abdomen and depositing frothy matter.

V. Influence of relative humidity of air and soil-moisture on incubation

Influence of relative humidity of air

Freshly laid eggs were removed and placed on cotton lint in glass tubes kept at constant relative humidities of 60, 80, 90, and 100 per cent and constant temperatures of 25, 33, 35 and 37°C. In a second series, batches of eggs which had completed about one-third development were placed in 80, 90 and 100 per cent relative humidities at room temperature (28°-30°C.). Results are set out in Table III.

It will be seen that at 90 per cent relative humidity and below, fresh eggs could not complete their development. With cent per cent relative humidity the incubation period was 11 days at 37°C., 11 to 12 days at 35°C., 12 days at 33°C., and a little less than 32 days at 25°C. The eggs which had

TABLE III

Incubation period at different temperatures and relative humidities

Temp. (°C.)	Relative humidity (per cent)	Date of oviposition (1931)	Date of hatching		Incubation period (days)	Remarks
			Tube No. 1	Tube No. 2		
			A. Freshly laid eggs			
37	100	21 Aug.	1 Sept.	1 Sept.	11	..
,,	90	do.	..	..	..	Shrivelled
,,	80	do.	..	..	..	do.
,,	60	do.	..	..	..	do.
35	100	do.	2 Sept.	1 Sept.	12	..
,,	90	do.	..	..	..	Shrivelled
,,	80	do.	..	..	..	do.
,,	60	do.	..	..	..	do.
33	100	do.	2 Sept.	2 Sept.	12	..
,,	90	do.	..	..	..	Shrivelled
,,	80	do.	..	..	..	do.
,,	60	do.	..	..	..	do.
25	100	do.	22 Sept.	22 Sept.	about 32	On 22 Sept. found hatched and dead : one living
,,	90	do.	..	..	..	Shrivelled
,,	80	do.	..	..	..	do.
			B. Eggs which had completed 1/3 of their development			
28–37	100	do.	4 Sept.	..	15	3 out of 5 hatched
,,	90	20 Aug.	4 Sept.	..	15	1 out of 5 hatched
,,	80	do.	6 Sept.	..	17	do.

completed one-third of their development took 15 days to complete the remaining two-thirds of the embryonic development in 90 as well as 100 per cent relative humidities at room temperature (28°—37°C.), but those kept in 80 per cent relative humidity hatched after 17 days, i.e. two days later than the eggs kept at the same temperature but incubated under optimum moisture conditions. Bodenheimer [1929] performed similar experiments on eggs which had completed one-third or two-thirds development. He also arrived at the conclusion that the eggs exposed to a partially saturated atmosphere, at a later stage of development, were able to complete their development.

Thus it may be concluded that freshly laid eggs can develop only in saturated atmosphere, a lower relative humidity being fatal for them. Partially developed eggs can complete their development in an atmosphere of lower relative humidity but the rate of development is considerably retarded.

Influence of deficient soil moisture

In *Locustana pardalina*, which undergoes a long diapause in the egg stage, Faure [1932] succeeded in hatching eggs which lay dormant in dry soil for 37 months, and according to Lounsbury [1915] they could be kept in a state of suspended animation for three and a half years. *Locustana pardalina* is characterised by the existence of a diapause in the egg stage and Faure mentions that the normal suspension of development takes place in spite of temperature and moisture being favourable for development. On the other hand *Schistocerca gregaria* has no egg-diapause, i.e. the development of the embryo is continuous provided the temperature and soil-moisture are favourable.

Statements have often been made to the effect that eggs of *Schistocerca gregaria* also remain undeveloped for a long time, and according to some for years, if kept under relatively dry conditions. Further that such eggs resume embryonic development when sufficient moisture becomes available to them. King [1921] mentions this possibility for *Schistocerca gregaria* but deplores lack of evidence. He suggests the possibility of oviposition occurring sometimes in dry earth and the eggs remaining unhatched until rain falls and provides them with the requisite moisture. This prolongation of the egg-stage has been reported to occur under natural conditions also. If this is so, it is evident that low temperature cannot be the determining factor. The threshold of development of the eggs of the Desert Locust is about 18°C. and in no region of the breeding area of the Desert Locust does a temperature of 18°C. or less prevail for a long period of time. Therefore it is likely that in such cases moisture is the controlling factor. No experimental evidence was available to support these statements in the case of *Schistocerca gregaria*. Experiments were designed to discover the influence of deficiency of moisture in soil on the development of eggs. The difficulties of these experiments have been pointed out. In what follows, results of successful experiments have been given. Four experiments were carried out with sandy soil and one each with loam, clay-loam and clay soil. In experiments 1 and 2 the sand used was dried in an oven at 60°C. In order to obtain maximum hygroscopic moisture, this sand was then kept in a dish in a desiccator with cent per cent relative humidity for two days and was occasionally stirred. To the soil, which had absorbed maximum hygroscopic moisture a measured quantity of water was added (Table IV) and the soil thoroughly mixed. Freshly laid

eggs were removed from the soil of the oviposition cages and placed about ½ inch below the soil of known moisture-contents in each dish. The dishes were then returned to the desiccator in which the atmosphere was always maintained, saturated with moisture, at room temperature. In all the dishes, including those that contained sand with maximum hygroscopic moisture, hatching took place without further moistening of the soil. Evidently the eggs in sand were in equilibrium with a fully saturated atmosphere and there was free water of condensation in the soil available to the eggs.

In experiment 3, (Table IV) one batch of eggs was placed in air-dry sand (dish *a*), i.e. in sand containing moisture below the maximum hygroscopic limit. The second batch was placed in moist sand to serve as control (dish *b*). After placing the eggs the mouths of both the dishes were sealed with wax and wax-paper. In another experiment (4) one batch of eggs was similarly sealed in sand containing only hygroscopic moisture in equilibrium with 80 per cent relative humidity (dish *a*) and another in moist soil to serve as control (dish *b*). On 14 May 1934 and 21 May 1934 when the respective control eggs had hatched, some water was added to the soil of the other dishes in which no hatching had taken place. The eggs in these dishes hatched on 25 May and 31 May respectively, i.e. 10 to 11 days after moistening.

Experiments 5, 6, and 7 were conducted on the same lines as experiments 1 and 2 except that the soil used was loam in experiment 5, clay loam in experiment 6 and clay in experiment 7. The eggs hatched in all the dishes in which the soil contained a higher percentage of moisture, while in the case of dishes containing low soil-moisture, namely dish *e* in experiment 5 and *b* and *c* in experiment 6, no hatching took place until the soil was moistened subsequently. It will be noticed that several of these dishes contained soil having a much higher percentage of water than the maximum hygroscopic moisture. The results of these experiments are given in Table IV.

TABLE IV

Influence of soil-moisture on the development of eggs (1934)

Experiment No.	Reference No.	Soil	Dish No.	Percentage of moisture added	Date of oviposition	Date of moistening	Date of hatching	Incubation period (days)	Temperature during experiment (°C.)	
									Average maximum	Average minimum
1	R22	Sandy	a	Saturated	4 Aug.	...	16 Aug.	12	34	33
	,,	,,	b	8·4	do.	...	17 ,,	13	,,	,,
	,,	,,	c	4·2	do.	...	18 ,,	14	,,	,,
	,,	,,	d	Max. hyg.	do.	...	21 ,,	17	,,	,,
2	P30	,,	a	4·6	4 Sept.	...	17 Sept.	13	,,	31·2

TABLE IV—*contd.*

Experiment No.	Reference No.	Soil	Dish No.	Percentage of moisture added	Date of oviposition	Date of moistening	Date of hatching	Incubation period (days)	Temperature during experiment (°C)	
									Average maximum	Average minimum
	P30	Sandy	b	4·6	4 Sept.	...	17 Sept.	13	34	31·2
	,,	,,	c	2·25	do.	...	19 Sept.	15	,,	,,
	,,	,,	d	2·25	do.	...	19-21 ,,	15–17	,,	,,
	,,	,,	e	Max. hyg.	do.	...	27-29 ,,	23–25	33·6	29
3	L456	,,	a	Air dry	27 April	14 May	25 May	28	30	Constant
	,,	,,	b	Control	do.	...	14 ,,	17	...	,,
4	L452	,,	a	Hyg. at 80 per cent R. H.	8 May	21 May	31 ,,	23	35	,,
	,,	,,	b	Control	do.	...	21 May	13	...	,,
5	Q16	Loam	a	30	18 July	...	31 July	13	36·1	33·0
	,,	,,	b	20	do.	...	do.	,,	,,	,,
	,,	,,	c	20	do.	...	do.	,,	,,	,,
	,,	,,	d	5	do.	...	3–4 Aug.	16–17	36·0	,,
	,,	,,	e	Max. hyg.	do.	...	6 Sept.	50	34·9	31·8
6	P30	Clay loam	a	13·3	4 Sept.	Attacked by fungus				
	,,	,,	b	6·6	do.	14 Nov.	24 Nov.	81	28·4	24·1
	,,	,,	c	6·6	do.	do.	do.	81	,,	,,
	,,	,,	d	Max. hyg.	do.	10 Nov.	Attacked by fungus			
7	Q14	Clay	a	18·7	7 Aug.	...	19 Aug.	12	34	33
	,,	,,	b	9·8	do.	...	21 Aug.	14	,,	33
	,,	,,	c	5·3	do.	21 Aug.	6 Sept.	30	32·5	31·7
	,,	,,	d	3·2	do.	do.	do.	30	,,	31·7
	,,	,,	e	Max. hyg.	do.	5 Nov.	Attacked by fungus			

Conclusions.—From Table IV it is evident that in sandy soil, containing maximum hygroscopic moisture and exposed to fully saturated atmosphere, the eggs of the desert locust were able to complete their development, although the incubation period was longer by five days as compared to the control eggs kept at optimum soil-moisture. Thus a comparative deficiency of moisture in soil resulted in a corresponding prolongation of the incubation period. When, however, the eggs were placed in soil more deficient in moisture, for example in air-dry sandy soil, i.e. in sand containing less than the maximum hygroscopic moisture, the development of eggs was arrested, and recommenced only when the soil was subsequently sufficiently moistened. Thus, in experiment 3, whilst the eggs in the control hatched after an incubation period of 17 days, those in air-dry sand had to be provided with more moisture to complete their development. These eggs hatched 11 days after the moisture was added. The incubation period at the temperature at which this experiment was conducted being 17 days, and the incubation period after the

subsequent addition of water being 11 days, it may be correct to assume that the development to the extent of six days of incubation at this particular temperature had taken place before the eggs were moistened. One may assume that the water required for this extent of development was available in the eggs. Similarly in experiment 4, eggs in moist sandy soil hatched after 13 days, while those in sandy soil, with hygroscopic moisture in equilibrium with 80 per cent relative humidity, remained unhatched and completed their development ten days after the soil was moistened subsequently. Thus during the 13 days that the eggs were in dry soil at 35°C. they had undergone development equal to three days' incubation under optimum conditions of moisture.

These experiments are of particular interest, because the soil and the eggs were kept in dishes the mouths of which had been sealed and, therefore, the humidity and soil-moisture were uniform throughout the experiment.

In the case of loam soil even when it contained maximum hygroscopic moisture (dish *e*, experiment 5) the development of eggs was completely arrested. The control eggs hatched after 13 days (dishes *a*, *b* and *c*) but these eggs (dish *e*) were unhatched after an incubation period of 34 days, when on 21 August they were moistened. They hatched on 6 September, i.e. 16* days after the date of moistening. Equally interesting is the case of dish *d* (experiment 5). Eggs were kept in loam soil to which, in addition to its maximum hygroscopic moisture, 5 per cent water by weight had been added. Hatching took place on 3 and 4 August, i.e. the incubation period was 15 to 16 days as against 13 days in loam soil to which in addition to the maximum hygroscopic moisture 10 per cent or more water (dishes *a*, *b* and *c*) had been provided from the very beginning. This prolongation of the incubation period by a few days shows that in loam soil 5 per cent water plus maximum hygroscopic moisture is a little less than the amount of moisture required for normal incubation. A comparison of the results of this experiment with those of experiments 1 to 4 shows that the quantity of water available for absorption by the eggs from soils of different nature varies although the various soils may contain the same percentage of water.

In clay-loam (experiment 6, dish *d*) and in clay (experiment 7, dish *e*) containing maximum hygroscopic moisture the eggs remained unhatched up to 67 days and 90 days respectively by the end of which they were found on examination to be healthy. On addition of water at the end of this period, however, they contracted fungus infection and none of the eggs could complete its development. In clay-loam (dishes *b* and *c*, experiment 6) to which, after the adsorption of maximum hygroscopic moisture, 6·6 per cent water had been added, the eggs laid on 4 September remained, so to say, dormant till 14 November, the date on which water was added to the soil. They hatched on 24 November, i.e. 81 days after the date of oviposition. In our experiments this is the maximum length of time over which the incubation period of the eggs of the desert locust was extended without loss of viability by providing conditions of moisture-deficiency in soil. Similarly in the case of clay (experiment 7) eggs placed in

*Sixteen days is about the normal incubation period at the temperature to which the eggs were subjected (Table IV).

dishes *c* and *d* (water 5·3 per cent and 3·2 per cent plus maximum hygroscopic moisture) remained unhatched up to 21 August, when moisture was added. They hatched on 6 September, i.e. 30 days after oviposition, the normal incubation period at the temperature at which this experiment was conducted being 12 days only.

The behaviour of soils of different texture is very interesting. In sandy soil eggs were able to complete their development when the soil contained only maximum hygroscopic moisture and the atmosphere to which it was exposed was kept saturated ; in heavier types of soils a percentage of moisture greater than the hygroscopic maximum was necessary for the complete development of eggs.

Under conditions of deficient soil-moisture, i.e. when the soil-moisture fell below a certain minimum percentage, varying with the texture of the soil, the embryonic development was completely arrested and recommenced only when the percentage of moisture was raised. The amount of moisture required increased with the heaviness of the soil.

These conclusions are obviously of very great importance. It has been established that in *Schistocerca gregaria* embryonic development is arrested by insufficiency of available moisture. Thus it is clear that, should dry conditions prevail in nature over a long period, it is not unlikely that eggs will remain dormant during the prolonged period of drought and hatch out only after precipitation.

Discussion.—The condition of the soil in which eggs were placed may be described thus. Soil is essentially a mass of loose particles of solid matter with a film of water surrounding them. The interspaces are thus occupied by water and air. The size of the interspaces depends on the texture of the soil. An egg placed in a soil will have a portion of its surface in contact with the soil particles and, therefore, in contact with the water fi m ; and a portion will also be exposed to the atmosphere in the soil and perhaps a film of water may get deposited upon the surface of the egg.

Moist soil exposed to a partially saturated atmosphere loses its moisture to a certain degree, varying with the texture of the soil, but this water is firmly held by the soil particles. It is well known that the remaining moisture, which is in equilibrium with the air and is known as hygroscopic moisture, cannot be utilized by plants. Wilting begins before the water-content of the soil falls below the hygroscopic limit because soils will rather retain such water than give it up to the plant. Nor can such water move from particle to particle [Hall, 1918]. The eggs of locusts placed in the soil can be likened to root hairs of plants. They would be drawing water from the film held round the soil particles. The force with which the film of water is held by the particles of soil depends upon the size and nature of the particles.

In most of the experiments described above the soil was exposed to a saturated atmosphere during the entire period of incubation. Since the air in a soil kept in an atmosphere of cent per cent relative humidity would also be saturated, the case would be similar with eggs exposed to a fully saturated atmosphere. If so, why did some of the eggs exposed to a saturated atmosphere in some of these experiments complete their development, while others did not ?

It seems to us that for normal development an egg must not only be exposed to a fully saturated atmosphere to prevent the loss of its own moisture,

but must also come in direct contact with water which it has to absorb. The fact that during the course of development eggs increase in weight supports this contention. In a saturated atmosphere even a small fall of temperature would result in a condensation of water in the soil. Such moisture being above the maximum hygroscopic limit may be easily available to eggs in sandy soils where on account of the comparatively bigger size of the sand particles it is rather loosely held, but in the case of heavy soils may be too firmly held to be easily absorbed by the eggs. The development of eggs would be affected accordingly. It seems very likely that, in cases where eggs hatched in a saturated atmosphere and in light soils having only the maximum hygroscopic moisture, it was this accidental precipitated water of condensation that provided the necessary moisture for embryonic development.

VI. Influence of saturated air on intermediate moult

It has been stated [Uvarov, 1928] that freshly emerging larvae cannot shed their intermediate moult in an atmosphere saturated with water vapour. It is argued that in moist air the chitin becomes too elastic and is difficult to burst.

Experiments were started to verify this statement. Fully incubated eggs were obtained from a field where they had been laid by a swarm, and transferred to a desiccator with cent per cent relative humidity on 15 August 1931. All the eggs hatched out on 16 and 17 August and the larvae shed their intermediate moults normally. A number of similar other experiments were performed with the same results. The question is of great practical significance because it may mean that after showers of rain, when the soil is giving out moisture and the air near the soil surface is fully saturated, the intermediate moult would not take place in nature. This, however, is contra-indicated by numerous actual observations.

VII. Influence of atmospheric humidity on hopper development

Three experiments were performed to determine the influence of relative humidity on the duration of the hopper stages of the desert locust. Experiment 1 was conducted at room temperature (average maximum 30·9°C., average minimum 27·1°C.) and at 45, 60, 80 and 100 per cent relative humidities, which were maintained by means of super-saturated solutions of salts. The hoppers were reared singly in Petri-dishes in the manner described by Zwölfer [1932]. For food they were provided with cabbage leaves which were renewed four times each day, when regular observation were recorded as to the stage of the hoppers. The frequent changing of the leaves however, caused some fluctuation in the percentage of humidity.

Experiment 2 was conducted on the same lines as experiment 1 except that the hoppers were reared crowded and at a constant temperature of 36°C. Only two humidities (85 per cent and 35 per cent) were tried.

In experiment 3, in order to avoid fluctuations of humidity, no leaves were placed with the hoppers. Four times each day, i.e. at 7, 12, 17 and 21 hours, the hoppers were transferred from their air-conditioned chambers to cages provided with fresh cabbage leaves and kept in a thermostat maintained at the corresponding temperature. An interval of an hour was

allowed for feeding, after which the hoppers were replaced in their respective chambers. During the feeding period the hoppers remained at an unknown but presumably higher humidity. The hoppers in this experiment were reared singly at a temperature of 36°C.

In experiment 1 (Table V) the average duration of the last two hopper stages at 45, 60 and 80 per cent relative humidities is the same, i.e. about 19 days. The one hopper that reached the adult stage at cent per cent relative humidity had a longer duration for the two stages, namely about 26 days. This insect was sickly throughout and for this reason it is not desirable to draw any inference. Saturated atmosphere, as has been shown earlier, causes disease among the adult locusts and it is probably equally unsuitable for the hopper stages of the desert locust.

The duration in experiment 2 also is the same for low (35 per cent) and high (85 per cent) relative humidities, i.e. on the average the hopper stage lasted 22 days in both the humidities.

In experiment 3 (Table V) a little lower relative humidity (23 per cent) was tried. It will be seen that the duration of the hopper stage in low humidity (23 per cent), which is lower than the one tried in experiments 1 and 2, is a little longer than in high humidity (80 per cent). Also, that the total average duration in both the humidities is longer than the normal duration at the temperature at which this experiment was conducted. This point will be referred to again.

TABLE V

Rate of growth of hoppers at different relative humidities

Expt. No.	Temp. (°C.)	Relative humidity	Duration of different stages (days)							No. of hoppers	Remarks
			I	II	III(*a*)	III(*b*)	IV	V	Total		
1	Average max. 30·9	100	...	...	...	...	9·5	17·3	26·8	1	The hoppers were reared singly
		80	...	...	...	...	8·0	11·4	19·4	7	
	Average min. 27·1	60	...	...	...	...	7·9	11·8	13·7	7	
		45	...	...	...	...	7·8	11·2	19·2	7	
2	36	85	3	4	3	...	4	8	22	26	The hoppers were reared crowded
	36	35	3	4	3	...	4	8	22	12	
3	36	80	...	...	6	7	5	10	28	1	Female
			...	...	5	6	6	10	27	1	Male
			...	...	6	7	6	10	29	1	Male
			...	...	6	6	7	10	29	1	Hoppers were reared singly
	36	23	...	...	6	6	7	10	29	1	Female
			...	...	9	6	6	10	31	1	Male
			...	...	...	14	7	9	30	1	Female
			...	...	6	...	7	9	22	1	Male
			...	...	...	13	7	9	29	1	Male
			...	...	...	13	9	9	31	1	Female
			...	...	7	...	5	12	24	1	Female
			...	...	...	13	7	10	30	1	Male
			...	...	6	7	7	11	31	1	Male

Key [1936] has studied the effect of humidities on the length of hopper stages in *Locusta migratoria migratorioides*. He selected 99-100 per cent relative humidity on the one side and 5-10 per cent on the other and concluded that with the decrease of relative humidity the durations of the stages increase. For ready reference, his figures are given below.

Length of stages in Locusta migratoria migratorioides (*days*)

Instar	High humidity (99-100 per cent)	Low humidity 5-10 per cent
I	6·8	12
II	6·4	12·0
III	5·9	8·6
IV	7·4	9·7
V	11·5	14·5

Attention may be drawn to the fact that these hoppers were supplied with ' small quantities of food once a day '.

On the other hand, Hamilton [1936] finds that *L. migratoria* has an optimum at about 60 per cent relative humidity at 90°-100°F. and that the duration increases as the relative humidity rises above or falls below this optimum. In the case of *Schistocerca gregaria* he finds that the optimum relative humidity at 90°F. is about 60 per cent and at 100°F. about 70 per cent. As in *L. migratoria*, so also in *S. gregaria* he finds that the duration of the hopper stages increases as the relative humidity diverges from this optimum. In his endeavour to avoid disturbing the humidity, Hamilton supplied food (grass or young wheat) only once a day to each cage.

In our experiments 1 and 2, where constant supply of green food was maintained, the duration of the hopper stages is about the same as is normal at the temperatures at which these experiments were conducted. While in experiment 3 where the insects had no food for 20 hours each day the duration of hopper stages at both the humidities is much longer than what it normally is at 36°C., the temperature at which this experiment was conducted. We thus conclude that this increase in the duration of the hopper stage is the result of under-feeding. In this experiment the increase is more pronounced in the case of hoppers at lower humidity. Possibly the greater loss of water from the body at the lower humidity is not made good during the four hours of feeding. Similarly, there must have been under-feeding in the case of hoppers in experiments of Key and Hamilton. The food must have dried up quicker at low relative humidity, resulting in greater under-feeding and prolongation of the hopper stages with decrease of amount of moisture in the air.

These experiments prove beyond doubt that the larval and imaginal development of *Schistocerca gregaria* is not appreciably affected by variations in relative humidity, provided the insect is able to get plenty of fresh food. Low humidity, prolongs the duration of hopper stage only indirectly, namely by making the food less congenial to the insect.

Summary

The sexual development of the adults is not inhibited by dry atmosphere if fresh food is available. Eggs are laid in soil sufficiently moist. Moisture has a marked influence on the incubation of *Schistocerca gregaria* eggs. Eggs

are not able to complete their development in a partially saturated atmosphere. Even with suitable temperatures the development may be arrested if the soil-moisture is deficient. In this way eggs were experimentally kept dormant for a period of 81 days under conditions of temperature at which normal incubation is only about three weeks. They recommenced development after moistening. These observations show the possibility of eggs remaining dormant for a long time in nature and hatching after rain.

The influence of low atmospheric humidity on hopper development is insignificant, provided a supply of fresh food, which is the normal source of intake of water, is available. A completely saturated atmosphere is, however, decidedly detrimental; it slackens larval development, shortens the adult life and increases mortality.

REFERENCES

Ballard, E.; Mistakawi, Eff. A. M. and Zoheiry, Eff. M. S. (1932). *Bull. Minist. Agric. (Egypt)* **110**, 1-149

Bodenheimer, F. S. (1930). *Z. Angew. Ent.* **15**, 435-557

Buxton, P. A. (1924). *Proc. Roy. Soc. Ser. B.* **96**, 123-31

Faure, J. C. (1932). *Bull. Ent. Res.* **23**, 293-428

Gough, L. H. (1916). *Report on the great invasion of locust in Egypt in 1915 and measures adopted to deal with it.* Minist. Agric. Egypt, Cairo

Hall, A. D. (1918). *'The soil'* (*London*), pp. 1-311

Hamilton, A. G. (1936). *Trans. R. Ent. Soc. (London)* **85**, 1-60

Husain, M. A. (1929). *Proc. Bd. Agric. Ind, 1929*, 187-91

Husain, M. A. and Ahmad, T. (1936). *Ind J. Agric. Sci.* **6**, 188-262; 624-71

Husain, M. A. Mathur, C. B. (1936). *Ind. J. Agric. Sci.* **6**, 263-67; 591-623

Key, K. H. L. (1936). *Bull. Ent. Res.* **27**, 77-85

King, H. H. (1921). *Sudan Ent. Bull.* **12**

Lean, O. B. (1931). *Bull. Ent. Res.* **22**, 551-70

Lounsbury, C. P. (1915). *S. Afr. J. Sci.* **12**

Nikolskv, V. V. (1925). *Bull. Dept. App. Ent.* **12** (In Russian)

Rao, Y. R. and Bhatia, D. R. (1939). *Ind. J. Agric. Sci.* **9**, 79-107

Roubaud, M. E. (1933). *C. R. Acad. Sci. (Paris)* **196**, 1139-42

Uvarov, B. P. (1928). *'Locusts and grasshoppers'* (London)

———— (1931). *Trans. Ent. Soc. (London)* **79**, 1-247

Zwölfer, W. (1932). *Z. Angew. Ent.* **19**, 497-513

BIONOMICS AND CONTROL OF THE FIG-TREE BORER, *BATOCERA RUFOMACULATA* DE GEER (COLEOPTERA: LAMIIDAE)

BY

M. AFZAL HUSAIN, M.A., I.A.S.

AND

M. ABDUL WAHID KHAN, M.Sc. (AGRI.)

Entomological Section, The Punjab Agricultural College, Lyallpur

(Received for publication on 19 July 1940)

(With Plate XLIV)

I. INTRODUCTORY

BATOCERA RUFOMACULATA De Geer is a very serious pest of fig trees, so much so that in certain localities fig growing is impossible, becuase of the ravages of this insect. For instance, in the Experimental Fruit Orchard at Lyallpur, 53 fig trees were planted in 1925 and by 1932 only three had survived the attacks of this borer.

Stebbing [1917] made some preliminary observations on this pest, but did not study its complete life-history. Beeson [1919] studied the food plants of this insect. Gardner [1927] described the mature larva and pupa. The observations made by us during the last few years are presented in this paper.

We acknowledge with thanks the information supplied by the Forest Entomologist, Dehra Dun, from his unpublished records, and we are further grateful to him for his permission to make use of it.

II. SYNONOMY [From Aurivillius, *Col. Cat.*, 73 : 127]

Batocera rufomaculata, De Geer, *Mem. Ins.*, *V*, 1775, p. 107. —Retzius, De Geer. *Gen. Spec.*, 1783, p. 138 .	India, Ceylon
———*cruentata*, Gmel. in L. *Syst. Nat.* ed. 13, I, 4, 1790, p. 1863	Madagascar
———*rubiginosa*, Voet, *Cat. Col.*, II, 1778, p. 34, t. 13, f. 53	Mauritius, Bourbon. German East Africa
———*rubra*, Maxwell-Lefroy, *Ind. Ins. Life*, 1909, p. 375, f. 245, 247.—Pierce, *Dangerous Ins.*, 1917, p. 103, f. 21.	
———*rubus*, Schröter, *Abhandl.*, I, 1776, p. 333, t. 2, f. 2.	
———*rubus*, Stebbing, *A Note on the Duki Fig Borer*, *Bull.* 10, 1907	
———*rubus*, var. *andamana*, Thoms., *Revue Zool.* (3) VI, 1878, p. 54.—Kriesche, *Revis*, p. 147 . . .	Andaman
———*rubus*, ab. *chlorinda*, Thoms., *Archives Ent.* I, 1857, p. 171 ; Monogr., p. 80.—Rits. *Notes Leyden Mus.* IX, 1887, p. 220.	East Indies

Batocera rubus, var. *diana*, Nonfr. *Deutsche Ent. Zeitschr.* 1891, p. 276.—Kriesche, *Revis*, p. 147 . . Tibet
———*rubus*, ab. *polli* Gah. *Ann. Mag. Nat. Hist.* (6) V, 1890, p. 55, t. 7, f. 2 . . . . . Ceylon
———*rubus*, ab. *thysbe*, Thoms. *Revue Zool.* (3) VI, 1878, p. 52 . . . . . Cochin China

III. Distribution

World distribution

B. rufomaculata is widely distributed in India, Ceylon, Malaya and East Africa. According to Duport [1914] it is present in the Far East and infests *Hevea* sp. Hutson [1920] has recorded it as a serious pest of *Artocarpus integrifolia* (jak tree) in Ceylon. It also occurs in Mauritius, Madagascar and Reunion. It got introduced into Torlota in 1914 and attacked and killed nearly all the native fig trees [Report of the Department of Agriculture, British Virgin Islands, 1920].

Distribution in India

According to Lefroy [1909] *B. rufomaculata* is found throughout the Indian plains. This has been confirmed by subsequent workers. Stebbing [1914] records it from Duki, Loralai (Baluchistan) (Col. C. A. Kemball) and Fort Sandeman (Major Roome *et mihi*). Fletcher [1914] found it throughout Southern India. Beeson [1919] has recorded it from Gorakhpur division of the United Provinces and Ramakrishna Ayyar [1923] from the Madras Presidency.

Distribution in the Punjab

It is probably distributed all over the province, but has, so far, been definitely recorded as a serious pest from Lyallpur, Sargodha, Hoshiarpur and the Kulu valley (on wild fig trees).

IV. Food plants

B. rufomaculata has a wide range of host plants belonging to 11 natural orders. A list of the host plants is given below :—

Food plants of Batocera rufomaculata *De Geer*

Food plant	Natural order	Country	Reference
Shorea robusta . . .	Dipterocarpaceæ	India . .	Unpublished records of the Forest Entomologist, Dehra Dun
Bombax malabaricum .	Malvaceæ .	,, . .	Beeson
Eriodendron anfractuosum .	,, .	Mauritius .	*Bull. Imp. Ist.*, XXIV, No. 1, 1926

Food plant	Natural order	Country	Reference
Sterculia colorata	Sterculiaceæ	India	Unpublished records of the Forest Entomologist, Dehra Dun
S. villosa	,,	,,	,,
Garuga pinnata	Burseraceæ	,,	,,
Buchanania latifolia	Anacardiceæ	,,	,,
Lannea grandis	,,	,,	,,
Mangifera indica	,,	Mauritius Virgin Islands	Wilson, Emmerz and Gebert
Odina wodier	,,	India	,, ,, ,,
Semecarpus anacardium	,,	,,	Unpublished records of the Forest Entomologist, Dehra Dun
Spondias magifera	,,	,,	,,
Moringa pterygosperma	Moringaceæ	,,	Beeson
Albizzia lebbek	Leguminosæ	,,	,,
Erythrina indica	,,	,,	Beeson & Fletcher
Barringtonia acutangula	Myrtaceæ	,,	Unpublished records of the Forest Entomologist, Dehra Dun
Adina cordifolia	Rubiaceæ	,,	,,
Hevea braziliensis	Euphorbiaceæ	,,	Beeson; Ayyar
Hevea sp.	,,	Far East	Duport
Artocarpus integrifolia	Urticaceæ	Ceylon	Hutson
A. incisa	,,	Ceylon	Hutson
Broussonetia papyrifera	,,	India	Unpublished records of the Forest Entomologist, Dehra Dun
Ficus asperrima	,,	,,	,,
F. bengalensis	,,	,,	,,
F. carica	,,	,,	Beeson
F. elastica	,,	,,	Wilson
F. glomerata	,,	,,	Beeson

Food plant	Natural order	Country	References
F. infectoria . . .	Urticaceæ	India	Unpublished records of the Forest Entomologist, Dehra Dun
F. pedunculata . .	,,	,, .	Wilson
F. religiosa . . .	,,	,, .	Unpublished records of the Forest Entomologist, Dehra Dun
F. tjakela . . .	,,	,, .	
Morus indica . . .	,,	,, .	
Almost any plant having a thick bark or possessing laticiferous vessles.	..	Virgin Islands	(Notes Insect pests Agric. Dept. Virgin Islands, Barbados. 1918-19)

In the Punjab it is the most destructive pest of fig trees and also attacks mango trees. Besides, it has been observed attacking apple trees (grown experimentally) at Lyallpur.

V. Description of the various stages

Stebbing [1907; 1914] has given a brief description of the full-grown grub and beetle. Gardner [1927] has given a fuller description of the full-grown grub and pupa.

Egg (*Plate XLIV, figs. 1-2*).—Oval, 5·5-6·8 mm. long and 1·8-2·3 mm. in diameter, chorion thick and leathery, surface very faintly marked with hexagonal impressions, colour dirty-white, micropylar end thicker with a circular depression bounded by a thick lip and surrounded by a brownish area.

Freshly-hatched grub (*Plate XLIV, figs. 3-7*).—Creamy-white in colour with head dark brown; slender, thickest in the thoracic region, gradually tapering towards the anal end, 8·4 mm. long and 2·7 mm. broad at the thorax; head 1·8 mm. long, 1·9 mm. broad; mandibles strong and dark in colour; labrum, labium and maxillæ covered with sharp bristles. Antennæ very minute, segmented, tipped with sensory papillæ. Pronotum with numerous strongly chitinised flattened denticles. Behind each spiracle there is a thick spine, directed backwards. Spiracles very characteristic, each possessing bilobed protuberance (in the later instars this structure disappears). Body covered all over with numerous minute spines.

Full-grown grub (*Plate XLIV, figs. 8-11*).—About 3 in. long, 0·8 in. wide at the thorax; body creamy-white, tapering towards the 8th segment and cylindrical further on; head dark brown with short antennæ; prothorax burnt-umber; thoracic legs rudimentary, extremely small, encircled with sharp minute bristles. Minute tubercles and denticles arranged on all the thoracic and abdominal segments. Spiracles nine on each side; just like oval pits of burnt-umber colour.

BATOCERA RUFOMACULATA DE GEER



FIG. 1. Egg



FIG. 2. Micropylar end of the egg (highly magnified)



FIG. 3. Antenna of freshly-hatched grub

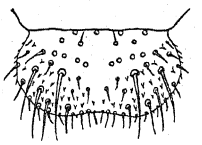


FIG. 4. Labrum of freshly-hatched grub

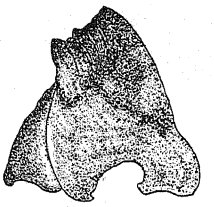


FIG. 5. Mandible of freshly-hatched grub

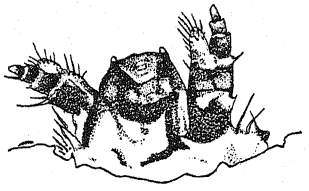


FIG. 6. Maxillae and labium of freshly-hatched grub

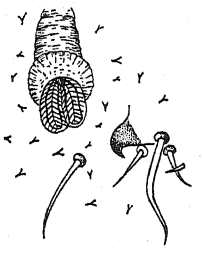


FIG. 7. Spiracle of freshly hatched grub, with spine and bilobed process

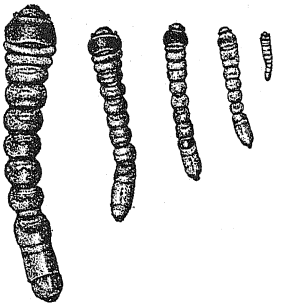


FIG. 8. Grubs of different stages—2nd instar to full-grown (For size see description)

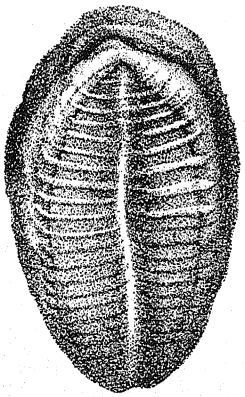


FIG. 9. Spiracle of a full-grown grub

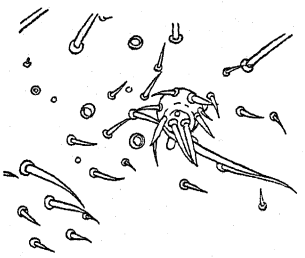


FIG. 10. Region of the meso-leg of a full-grown grub showing a rudimentary leg

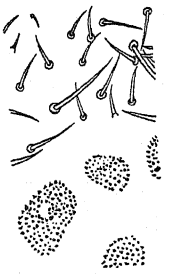


FIG. 11. Denticles and minute tubercles on ventral surface of the 9th segment of full-grown grub



FIG. 12. Pupa (side view)

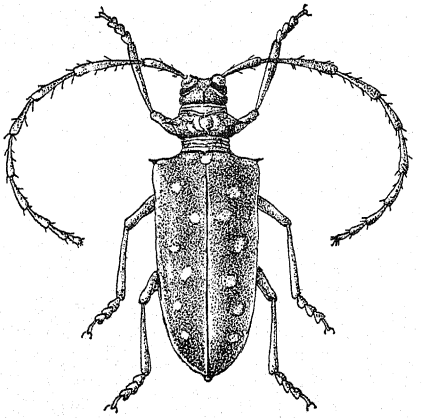


FIG. 13. Adult beetle (For size see description)

Pupa (*Plate XLIV, fig. 12*).—50 mm. long, 22 mm. broad across the thorax; when freshly formed creamy white, later on changing to pale brown. Head slightly deflected, antennæ very long, pass along the thorax on each side and then make a spiral over the respective meta-leg. First two pairs of legs folded over the wing pads and the meta-legs folded below the tips of wing pads. Pronotum shield-shaped and bears one protuberance on each side. Abdominal tip tapering and curved with a sharp upward bend.

Beetle (*Plate XLIV, fig. 13*).—Female 1·9 × 0·7 in., male 1·6 × 0·6 in.; stout; dark brown covered with yellow-ochre pubescence; ventro-lateral sides with a white strip running lengthwise; scutellum white; pronotum with two kidney-shaped orange-yellow spots. Cephalic region of elytra with numerous dark tubercles and one small, sharp tooth on each shoulder. Lateral margins of elytra dark. Light yellow spots of variable numbers on each elytra. Antennæ long, dark brown, 11-segmented, 3rd segment with a row of small teeth on inner edge. Prothorax with a sharp pointed, stout tooth on each side in the middle.

Distinguishing characters of the male and female beetles

Male	Female
1. Antennæ, if folded back, their 3 segments reach beyond the abdominal tip.	1. Antennæ do not approach or exceed the hinder end.
2. The anal end is brown and much wider than that of the female.	2. The anal end is dark black and narrower than that of the male.
3. Elytra reach the anal end.	3. Elytra do not reach the anal end.

VI. Seasonal history

In South India the beetles seem to emerge about the beginning of the rains, in May and October [Fletcher, 1914]. In Baluchistan this insect is apparently most plentiful in July [Stebbing, 1907]. At Lyallpur, in 1932, the beetles started emerging about the end of May and continued to emerge till the end of August. In 1933 the emergence started early in May—the first beetle was seen actually emerging out of a stem on 2 May. The emergence continued till the end of August. The last beetle was observed coming out of a stem on 29 August 1933. The beetles thus emerge during the summer months, and the emergence is at its maximum during the months of July and August, i.e. during the monsoon rains. It may, however, be mentioned that a male beetle emerged from a caged tree in the insectary on 29 October. Usually, however, the beetles do not emerge after August.†

The adult is long-lived and beetles have lived in captivity in the laboratory as long as five months, viz. from June to the beginning of November. The Forest Entomologist has recorded eight months as the maximum life of the beetle in captivity (unpublished records). Thus the egg-laying period may extend from May to the end of October or even the beginning of November. The grub stage is met with in the stem of the attacked trees throughout the year and the pupal stage from November onward.

†The emergence period in North India is from March to August; 50 per cent of the beetles emerge in May and 30 per cent in June (Unpublished records of the Forest Entomologist).

The seasonal history may be summarised as follows :—

May to August . .	Beetles emerge, eggs and grubs are met with, as well as pupæ of the last year are met with.
August to October .	Oviposition continues, grubs are met with.
November . .	Grubs of various stages and pupæ are met with.
December to April .	Grubs in the resting stage and pupæ are met with. In March, however, mostly the pupal stage is present. Rarely, full formed beetles are found in the resting stage within the pupal chambers (observed in the Kulu Valley).

VII. Life-history

Oviposition

The eggs are laid singly. The female beetle cuts, by the repeated action of its strong vertical, sickle-shaped mandibles, a slightly curved transverse slit in the bark of the fig tree. Through the slit thus made the eggs are pushed down under the bark (usually they are completely pushed under the bark). Generally the eggs are deposited in the stem, most frequently near the base, but occasionally they may be laid in the branches. Stebbing [1907] observed the incisions made in the bark by the beetles but was not able to locate the eggs. He stated, ' The eggs have not yet been observed, but they are probably laid either singly or in little clusters on the outside of the bark of the tree or incisions made by the beetle in the outer bark ..... ' In Leaflet No. 10 [1918] of the Department of Agriculture Reduit (Mauritius), it is stated ' The eggs are deposited singly in the cracks in the bark, in which the young larvæ remain for the greater part of their life.' According to our observations the eggs are not laid in natural cracks of the bark, but are always laid pushed well under the bark, through the incisions definitely made by the beetle for the purpose.

It has been observed that after an egg has been laid, the female rubs the anal end over the slit from side to side, excreting at the same time a colourless liquid with which the mouth of the slit is covered over.

The method of oviposition would indicate that eggs can only be laid in living plants. However, according to the observations of the Forest Entomologist, oviposition occurs on dead as well as living trees that are not in good health and on roots of trees exposed by erosion, etc. (unpublished records of the Forest Entomologist). This requires confirmation. So far as our observations go the eggs are never laid on dead trees.

The eggs may be laid at any time during day or night.

Number of eggs laid by a female

Five pairs of freshly emerged beetles were liberated on caged fig trees on 22 August 1933, and transferred from one tree to another, and the record of eggs laid by them is given in Tables I and II. From 23 August 1933 to 26 September 1933 these five pairs were kept together and, therefore, their egg-laying record is collective. From 26 September 1933 onward each pair was kept separate and transferred from one cage to another every day and supplied with a fresh fig branch. The largest number of eggs laid by one female in 24 hours was seven. These five beetles laid 513 eggs in all. The Forest Entomlogist, Dehra Dun records up to 200 eggs laid by a female (Unpublished records).

Table I

Record of egg-laying of five females of Batocera rufomaculata *De Geer during 1933*

Date of oviposition	Number of eggs laid by 5 females	Total	Date of oviposition	Number of eggs laid by 5 females	Total
1st tree—			11 Sept. . . .	6	
24 Aug. . . .	4	4	13 „ . . .	5	
2nd tree—			15 „ . . .	4	
26 Aug. . . .	7		17 „ . . .	6	25
27 „ . . .	6		5th tree—		
28 „ . . .	8	21	19 Sept. . . .	10	
3rd tree—			20 „ . . .	25	
3 Sept. . . .	4		21 „ . . .	35	
5 „ . . .	6		22 „ . . .	15	
7 „ . . .	8	18	23 „ . . .	20	
4th tree—			24 „ . . .	25	130
10 Sept. . . .	4			Total	198

Table II

Record of egg-laying of the same five females after separating them in different cages from 26 September 1933 onward

Date of egg-laying	Number of eggs laid by different females				
	No. 1	No. 2	No. 3	No. 4	No. 5
27 Sept.	3	1	3	..	..
28 „	5	2	4	7	7
29 „	..	2	2	..	..

TABLE II—*contd.*

Date of egg-laying	Number of eggs laid by different females				
	No. 1	No. 2	No. 3	No. 4	No. 5
30 Sept.	1	4	2	4	3
1 Oct.	1	4	5	6	5
2 „	..	1	4	2	4
3 „	3	..	3	4	3
4 „	2	..	1	4	2
5 „	..	2	..	1	1
6 „	..	..	..	..	1
7 „	7	3	5	9	4
8 „	4	..	5	5	4
9 „	4	4	5	5	3
10 „	1	1	4	1	1
11 „	1	..	1	2	..
12 „	1	..	..	..	..
13 „	3	1	5	4	2
14 „	2	2	5	3	5
15 „	2	1	1	4	1
16 „	..	..	1	2	2
17 „	..	..	1	..	..
18 „	..	..	..	..	..
19 „	1	1	1	1	2
20 „	2	1	5	2	4
21 „	2	..	2	2	..
22 „	1	1	3	2	..
23 „	..	..	6	1	2
24 „	..	..	3	..	..

TABLE II—*concld.*

Date of egg-laying	Number of eggs laid by different females				
	No. 1	No. 2	No. 3	No. 4	No. 5
25 Oct.	1	1	5	1	5
26 „	..	1	2	1	2
27 „	..	..	2	..	..
28 „	Died	..	..	..	..
29 „		..	2	..	1
30 „		..	3	..	..
31 „		..	3	..	..
1 Nov.		..	3	..	..
2 „		Died	Died	Died	1
3 „					Died
Total .	47	33	97	73	65

Hatching

The grub hatches out from the end of the egg which is towards the opening of the slit, i.e. the micropylar end, but it tunnels into the bark without exposing itself. In case the egg projects beyond the slit, the grub on hatching is unable to bore into the bark and perishes.

Conditions necessary for hatching

It has been observed that moisture is essential for hatching, and embedded in the tissue of the plant, the egg gets the moisture required by it. Some of the eggs were taken out and kept in glass tubes without moisture, and some in a tube with a moist piece of cloth. The eggs in the dry tubes shrivelled up, while those under moist conditions hatched out.

Incubation period

The duration of the egg stage varies from 7 to 14 days, most of the eggs hatching within seven to ten days (Table III).

Feeding habits of the grub

The grub feeds on the inner portion of the bark and xylem. Its path is zigzag. Evidently the grub cuts more fibres than it can actually eat, and these fibres are thrown out. It has been stated by Stebbing [1914] that ' the

tunnel is blocked behind by the excreta of the larvæ, the portion occupied by the latter being full of sap'. It has been definitely ascertained that the tunnel is filled up not by mere excreta, but by excreta mixed up with a large amount of fibrous matter, which has not passed through the alimentary canal of the grub. By shaking material from the tunnel of a grub in a small amount of water, the fibre and small rounded grains of excreta can be easily distinguished. The excreta just coming out from the anal end of the grub was also examined and compared with the fibrous matter in the tunnel and was found to be different.

The grubs feed upon the inner portion of the bark for a considerable period, making a zigzag tunnel, and filling it behind with frass. They enter into the wood when they are sufficiently grown up. It has also been observed that if an egg is deposited on a small branch, then the grub enters into the wood very soon and its path is not zigzag. It enters into the wood of the branch and makes a straight tunnel into the heart of the wood.

Duration of the grub stage

The duration of the grub stage varies from about three to over six months (Table III). Fletcher [1914] states ' the larval stage probably lasts over a long time—possibly several years '. Evidently this is not correct, or at any rate is not usual.

Resting

The grubs become full-grown by about the end of September to the middle of November and prepare elliptical chambers for resting and pupation, stop feeding and remain in the resting stage throughout the winter. In rare cases, however, they may pupate in November and the beetles are formed. These beetles continue in the resting stage throughout the winter and right up to the end of April.

Pupation

The pupation takes place in an elliptical chamber within the stem, usually at a distance of about two inches from the surface, therefore the adult beetle has to cut its way out. The pupa lies naked inside the chamber.

Duration of the resting and pupal stage

The duration of the resting and pupal stages varies from about four to seven months (Table III). This includes the resting larval stage and the immature beetle stage. Stebbing [1914] considered the pupal stage as 3 to 3½ months in duration. According to the observations made by the Forest Entomologist, Dehra Dun, the pupal period lasts for three to four weeks and is followed by an immature beetle stage of variable duration (unpublished records).

Emergence of the beetle

The beetle emerges by cutting out its own passage starting from the pupal chamber and terminating in a circular exit hole of about 0·7 to 0·8 in. diameter. The tunnel is always of variable length.

TABLE III

Duration of various stages of Batocera rufomaculata *De Geer*

Date of caging the beetles	Date of egg-laying	Date of hatching	Duration of egg stage (days)	Date of* entering the resting stage	Duration of the active larval stage (days)	Date of emergence	Duration† of resting and pupal stages (months)	Total life-cycle (months)
2 June 1932 .	5 June 1932 .	17 June 1932 .	12	26 Sept. 1932 . to 15 Nov. 1932 .	99 to 148	29 Oct. 1932 . 2 May 1933 . 8 „ 1933 12 „ 1933 30 „ 1933	6 to 7	11 to 12
10 Sept. 1932 .	16 Sept. 1932 .	30 Sept. 1932 .	14	2 Apr. 1933 .	182	4 Aug. 1933 .	4·07	10·6
22 Aug. 1933 .	24 Aug. 1933 .	31 Aug. 1933 .	7	March 1934 .	About 180 days	July and August 1934	4 to 5	10 to 12
Do. .	26 Aug. 1933 .	2 Sept. 1933 .	8	Do. .	Do. .	Do. .	4 to 5	10 to 12
Do. .	3 Sept. 1933 .	12 Sept. 1933 .	9	Do. .	Do. .	Do. .	4 to 5	10 to 12
Do. .	15 Sept. 1933 .	25 Sept. 1933 .	10	Do. .	Do. .	Do. .	4 to 5	10 to 12
Do. .	19 Sept. 1933 .	26 Sept. 1933 .	7	Do. .	Do. .	Do. .	4 to 5	10 to 12

* Date of entering the resting stage means the date when the pupal chamber has been completed and the grub starts rest before pupation.

† The duration of the resting and pupal stage includes resting larval, pupal and immature beetle stages.

Number of broods

It is evident from the above that there is only a single brood in a year.

VIII. Damage

Damage done by the beetle

The beetle feeds upon the bark of young twigs, petioles of leaves and even the fruit of fig trees. The buds of the attacked twigs wither, the shoots remain stunted, and the leaves of which the petioles are damaged fall off. However, the damage done by the beetle is not of any great consequence. It is the grub stage which is the most harmful.

Damage done by the grubs to the tree

The grubs do not kill the tree outright and this led Stebbing [1914] to remark, ' Up to the present it has not been definitely proved that this pest kills the trees '. Even a severely attacked tree may continue to live for a considerable time, even years, but finally it dries up. The tree only succumbs to the attack when the inner portion of the bark has been totally destroyed from all round the stem. If a branch is attacked, that branch alone would dry up. In cases of severe attack, the bark cracks, and the inner wood is damaged by numerous galleries. It should, however, be noted that if a grub mainly tunnels the wood and the bark remains intact, the tree is not killed.

In our Field Laboratory six beetles were liberated on a fig tree on 2 June 1932. They laid several eggs, the grubs continued to feed upon the stem and ultimately the tree completely dried up. Besides, as stated previously there were 53 fig trees in the Experimental Fruit Garden at Lyallpur. Out of these only three survived an onslaught of this pest. Further, it is a matter of common observation that fig trees do not live very long because of this pest. The report of the Department of Agriculture, British Virgin Islands [1920] also shows that the pest has destroyed nearly all the native fig trees in that island.

IX. Symptoms of attack

Early symptoms

Only a trained eye can discover the early symptoms of attack.

As stated above, the female beetle makes very characteristic transverse slits on the main stem, more frequently near the base and sometimes on the thick limbs of the fig plant. They are moist on account of the sap oozing out of the fresh cuts. On opening up these slits one can discover the eggs.

After a few days a dark brown streak, consisting of the fibrous matter mixed up with the excreta of the freshly hatched grub, is seen coming out of the hole of entrance of grub. As the attack progresses, the quantities of excreta and fibrous matter passed out increase and sap also oozes out of the hole.

When the beetles are about, a very careful examination of the bark, the petiole of the leaves, and the fruit may reveal marks of feeding. A more careful search among the branches may reveal the beetle itself. The beetle when caught makes a shrill piercing noise, which it produces by rubbing the scraper on the hind edge of its pronotum over the file on the mesonotum.

Later symptoms

When the attack has progressed further one can see, even from a distance, a mass of woody frass below an attacked portion of the stem or a branch. The bark over the attacked portion cracks and most of woody fibre filling the burrow thus becomes visible. In case of an old or severe attack one can see numerous circular holes on the trunk or the branch, indicating that the beetles have emerged out of these.

X. Preventive and protective measures

Three different methods were tried in May 1932, just before the egg-laying period to protect the plants.

(*a*) Wire gauze (1/16 in. mesh) was wrapped round the stem of 22 fig trees. No attack appeared on the protected parts but the beetles attacked the unprotected portions.

(*b*) Lime was applied to the stem of eight trees, but this proved of no avail.

(*c*) Coal tar was similarly applied to eight trees, but this could protect the treated portion only. Coal tar painted papers were wrapped on the stem of a plant under a cage and beetles liberated in this. It was found that no eggs were laid.

Trial of spraying the stem and main branches with repellent mixtures.

In an orchard at Nurpur near Pathankot, there has been a constant trouble of the fig borer for the last several years on mango and fig trees. Several trees have been killed from year to year, and the trouble was noticed to be very serious early in 1939. The attacked trees were treated by plugging the tunnels with cotton-wool soaked in kerosene oil and plastering with mud; all the grubs were killed by this method. For the prevention of any further attack five sprayings were given with repellent mixtures so as to provide a poisonous coating on the bark. The treatment resulted in a complete protection to the trees. The total number of trees thus treated was 110 mango and 10 fig trees. Sprayings were started just before the oviposition period and continued throughout the summer at varying intervals.

As a result of the sprayings, no oviposition was noticed on any tree except in the case of one fig tree on an unsprayed area of a branch, which rather proved the efficacy of the treatment.

It is evident, therefore, that by using wire gauze (1/16 in. mesh) or coal-tar-painted paper and spraying on the stem and thick branches with repellent mixtures the stem of a fig tree can be protected against oviposition.

Where the attack by the pest is bad, all trees which are heavily infested and are drying up should be cut and burnt. Dead branches of trees should also be cut and similarly destroyed.

Any beetles seen in garden should be captured and killed. Beetles can be collected during daytime feeding upon the top-shoots.

Trees should be examined frequently from May to October, and any fresh attack on a branch or a stem attended to.

If some fibrous substance is coming out of a slit, then a larva is very likely to be present. In early stages it lies very close to the opening of the slit and can be taken out by opening the slit with a sharp knife.

XI. Control

Injecting kerosene oil.—Most successful results were obtained by injecting kerosene oil by means of a syringe into the holes in the stem of trees having linear tunnels made by the grubs.

In an experiment eight trees were thus treated with kerosene oil. The tunnels made by the grubs were cleaned out by means of a wire and the oil was syringed so as to reach the wood. One and a half bottles of kerosene oil costing three annas and nine pies were used for eight trees, the cost per tree coming to six pies. The holes were closed with mud after this treatment. In cases where the tunnel is zigzag it was cleaned as far as possible and plugged with cotton-wool soaked in kerosene oil and finally plastered with mud. Fletcher [1914] recommends a mixture of two parts of chloroform and one part of creosote to be injected into the holes. The liquid may either be injected by means of a syringe or an ordinary bicycle oiling can. Another method is to soak cotton-wool in kerosene oil or chloroform and creosote mixture and plug the hole with it.

Potassium cyanide.—At Jahankhelan in the Hoshiarpur district, in an orchard of 33 fig trees, 11 were found attacked by *Batocera* grubs. Three trees were treated by introducing into each hole in the region of wood a small crystal of potassium cyanide weighing about 2 grains. The holes were closed with mud. The grubs were killed and no injury was done to the trees. This method, however, requires very careful manipulation.

XII. Summary

The various stages of *Batocera rufomaculata* de Geer are described.

The female cuts by means of its mandibles a transverse slit in the bark and pushes the egg through this slit. The grub hatches out in 7 to 14 days and tunnels into the bark, following a zigzag path. The tunnel is filled up with chewed fibre and fæcal matter. The active grub stage lasts for about six months and when full grown, the grub prepares an elliptical pupal chamber and enters on resting stage prior to pupation, when it stops feeding. Pupation takes place inside the chamber and the beetle emerges in about four months by cutting out its own passage. There is only one brood in the year. The beetles appear every year from May to the end of August and continue living up to November.

The attack by the beetles can be prevented by protecting the stem with coal-tar-painted paper or wire gauze (1/16 in. mesh) or spraying on the stem and thicker part of branches with a strong repellent mixture. By killing young larvæ, or by injecting kerosene oil or chloroform-creosote mixture into the holes from which frass is coming out or by cleaning the tunnel and plugging it with cotton-wool soaked in kerosene oil and finally plastering the hole with mud, the pest can also be controlled.

REFERENCES

Anonymous, (1918-19). *Notes in connection with insect pests, Agr. Dept. Virgin Islands, Barbados*, 7-8

————(1920-22). *Planter's Chron.* **15**

————(1926). *Bull. Imp. Ins. (London)* **24**, 18-36

————(1930). *Adm. Rept. Dir. Agric. Ceylon (Colombo)*, 61

Beeson, C. F. E. (1919). *Ind. For.* **14**, 488-95
——————(1924). *Proc. 5th. Ent. Meet.* (*Pusa*)
Duport, L. (1914). *Extract due Bull. Econ. Indochine, Hanio Haiphong Nanvella Ser.* **105**, 989-90
D'Emerez, De Charmy D. and Gebert, S. (1921). *Bull. Ent. Res.* **12**
Fletcher, T. B. (1914). '*Some South Indian insects*': Madras
Hutson, J. C. (1919). *Ceylon Dept. Agric. Adm. Rept.*, 1919
Lefroy, H. M. (1909). '*Indian insect life*', p. 375
Linneaus. C. von, (1758). *Syst. Nat.* ed. **10**, 390
——————, (1767). *Syst. Nat.* ed. **12**, 625
Ramakrishna Ayyar, T. V. (1923). *Agric. J. Ind.* **18**, 50-9
Stebbing, E. P. (1907). *Forest Bull.* **10**
——————(1914). '*Indian forest insects*', pp. 362-5
Wilson C. E. (1918). *Mauritius Dept. Agric.* (*Reduit*) *Leaflet* **10**
——————(1920-21). *Rept. Entomologist Virgin Islands Agric. Exp. Sta. Washington, D. C.*, pp. 20-35

THE INFLUENCE OF THE RAINFALL DISTRIBUTION ON THE COTTON YIELDS AT THE GOVERNMENT EXPERIMENTAL FARMS AT AKOLA AND JALGAON*

BY

R. J. KALAMKAR, B.Sc., B.Ag., Ph.D.

AND

V. SATAKOPAN, M.A.

Agricultural Meteorology Section, Meteorological Office, Poona

(Received for publication 21 June 1940)

(With three text-figures)

THE Bombay province and the Central Provinces and Berar are important cotton-growing tracts covering about 60 per cent of the total area under cotton in India. In these two provinces the crop is grown extensively in the East and West Khandesh districts of the Bombay province and the districts of Berar. Over this tract the climate and soil characteristics are more or less the same and so the season, the crop and the methods of cultivation are more or less similar. Cotton is generally sown by the second week of June, usually after the first fall of 2 in. of rain. Its period of quickest growth is during August-September. The crop becomes ready for first picking during October. About four pickings are obtained during the growth period of the crop. The Khandesh crop is early by about a fortnight.

Akola is a representative centre of the Berar tract and has a Government experimental farm for the study of the cotton crop. The farm was opened in June 1906 and regular work began in 1907. The soil of the farm is a deep black loam typical of the Berar tract. A series of cotton yield-data extending over a period of 28 years commencing from the season 1907-08 was kindly supplied by the Director of Agriculure, Central Provinces and Berar.

Jalgaon is situated in the East Khandesh district of the Bombay province and has a Government experimental farm for the study of the cotton crop, which was started in 1913-14. The soil of the farm is deep black. A series of 23 years' data on cotton-yield from 1913-14 was kindly made available by the Director of Agriculture, Bombay province.

The above two series of yield-data form the basis of this paper in investigating the influence of the quantity and distribution of rainfall on the cotton yield. The yield-data of cotton supplied relate to the average yield per acre over the farm as a whole and not to any one particular plot. The results of investigation on the Akola series alone have been already discussed by Kalamkar and Satakopan [1935].

* This investigation was undertaken in the Agricultural Meteorology Section, Meteorological Office, Poona, when the section was financed by the Imperial Council of Agricultural Research.

The yields of seed cotton in lb. per acre at the two farms are given in Table I. The average yield of seed cotton at the Akola Farm was 443 lb. per acre, with a standard deviation of 213 lb., and at Jalgaon it was 485 lb. per acre with a standard deviation of 165 lb. The yields were highly variable, their coefficients of variability being 48 and 34 respectively for the two farms.

The two series of yields were subjected to an examination for secular changes by fitting polynomials of the 5th degree [Fisher, 1925]. The values of x's for the two series are shown below :—.

	Akola	Jalgaon
Mean	442·9	484·7
x'_2 . . .	+280·7	—68·2
x'_3 . . .	+131·2	—173·0
x'_4 . . .	+19·0	+143·6
x'_5 . . .	—346·5	—52·5
x'_6 . . .	+164·8	+87·9
Standard residue .	211·0	176·9

For both the series none of the values of the x's is significant when compared with the standard residue, indicating that there are no secular changes in the series of yields.

For studying the effect of rainfall on the yield of cotton the period 22nd May to 23rd October is considered. This period is divided into 31 subperiods, each of five days. The total rainfall in each five-day period is computed from the daily rainfall records of the two stations for all the years required. A fixed calendar date rather than the date of sowing has been used as a reference point for the season for convenience. The choice of a five-day period for a unit of time, although arbitrary, is believed to be fine enough to represent the rainfall distribution and also its effect in general on the growth of the crop, and the agricultural operations, such as interculture, weeding, etc.

The 31 five-day rainfall figures for each year have been fitted with a polynomial of the 5th degree and a set of six constants a', b', c', d', e' and f' is obtained to represent the distribution. These constants which are given in Tables II (a) and II (b) for the two stations are later used as independent variates with which the crop yield is correlated to obtain a regressional integral according to the method developed by Fisher [1924]. Each series of the distribution constants in Tables II (a) and (b) has been examined for the presence of secular changes over their respective periods. Tables III-a and III-b give the values of x's together with their standard residues.

TABLE I

Yield of seed cotton in lb. per acre at Akola and Jalgaon

Year	Yield at Akola	Yield at Jalgaon
1907-08	258	..
1908-09	342	..
1909-10	504	..
1910-11	259	..
1911-12	570	..
1912-13	486	..
1913-14	509	277
1914-15	564	387
1915-16	682	777
1916-17	60	623
1917-18	179	112
1918-19	218	596
1919-20	771	545
1920-21	55	598
1921-22	513	626
1922-23	216	484
1923-24	456	603
1924-25	334	537
1925-26	393	352
1926-27	378	573
1927-28	782	441
1928-29	662	360
1929-30	753	614
1930-31	657	642
1931-32	150	153
1932-33	583	529
1933-34	433	527
1934-35	634	290
1935-36	..	502
Mean	443	485
S. D.	213	165
C. of V.	48	34

It is interesting to compare the mean values of the rainfall distribution constants for the two stations given in the first rows of Tables III-*a* and III-*b*. The mean values for the two stations show good agreement and the differences will be seen to be not significant in the light of the pooled estimates of errors. This indicates that the average amount as well as distribution of rainfall for the two stations are more or less similar.

TABLE II-*a*

Rainfall distribution constants—Akola (unit $\frac{1}{1000}$ *in.)*

Year	a'	b'	c'	d'	e'	f'
1907	620	—122	—157	+73	+19	—4
1908	1,108	—170	—249	+103	—40	—4
1909	784	—96	—142	+39	—30	—5
1910	1,105	—38	—178	+5	—58	+8
1911	623	—129	—109	+57	—13	—6
1912	608	—95	—154	+84	+6	—29
1913	869	—133	—210	+67	0	+1
1914	859	—15	—143	—27	—72	+23
1915	867	—18	—177	+65	—12	—46
1916	1,334	—40	—169	+51	+22	+30
1917	936	+46	—38	—45	—48	—4
1918	398	—175	+15	+9	+3	—7
1919	824	—168	—62	+60	—68	—1
1920	338	—37	—63	+27	—25	—3
1921	773	—52	—147	+9	—24	+5
1922	954	—135	—240	+113	+3	—72
1923	707	+60	—139	—11	—45	—5
1924	1,107	+219	—176	—100	+8	+50
1925	622	—88	—119	+34	+38	—1
1926	987	—101	—306	+89	+57	—37
1927	912	+22	—19	+47	—164	—70
1928	880	+56	—30	0	—76	+50
1929	681	—209	—67	+131	—112	—7
1930	892	+84	—134	—124	—73	+41
1931	1,130	+256	—106	—6	—49	—80
1932	830	—7	—207	+30	+21	0
1933	1,215	—71	—156	+4	—35	+35
1934	1,056	—67	—318	+45	+83	—3

TABLE II-*b*

Rainfall distribution constants—Jalgaon (unit $\frac{1}{1000}$ in.)

Year	*a'*	*b'*	*c'*	*d'*	*e'*	*f'*
1913-14	904	—146	—230	+78	+12	—9
1914-15	1,197	—69	—265	+36	—30	—28
1915-16	966	+78	—90	+83	—67	—92
1916-17	995	—41	—150	+92	+38	—5
1917-18	778	+125	—19	—70	—70	—26
1918-19	421	—123	—55	+37	—4	—7
1919-20	966	—95	—61	+1	—44	—2
1920-21	399	—56	—101	+58	—2	—35
1921-22	928	—156	—183	+82	—28	—2
1922-23	686	—15	—113	+13	—73	—16
1923-24	1,014	—32	—285	+66	+21	—77
1924-25	787	+66	—30	+38	—30	—15
1925-26	526	—83	—126	+30	+29	—10
1926-27	705	—15	—221	—13	56	+25
1927-28	855	—69	—142	+98	—59	—73
1928-29	787	+86	—103	+24	—41	—39
1929-30	697	—217	—78	+141	—95	—17
1930-31	1,380	+46	—225	—119	—138	+70
1931-32	1,659	+364	—61	+50	—106	—137
1932 33	937	—35	—248	+45	+23	—11
1933-34	1,201	—74	—137	—119	—43	+84
1934-35	1,484	—135	—407	+42	+71	+36
1935-36	823	—50	—213	+47	—13	—26

TABLE III

Secular changes in rainfall constants

——	a'	b'	c'	d'	e'	f'
			(*a*) *Akola*			
Mean . .	+857·82	—43·68	—142·86	+29·61	—24·43	—5·03
x'_2 . . .	+254·01	+219·11	—0·14	—77·03	—11·67	+0·76
x'_3 . . .	+311·49	—52·94	—159·39	+39·70	+34·11	+13·01
x'_4 . . .	+170·05	—45·14	—52·00	—16·98	+67·71	+13·91
x'_5 . . .	—92·17	—101·54	—78·36	+20·98	+113·05	+5·72
x'_6 . .	+73·20	—53·04	—153·93	+30·38	+53·65	—2·16
S. R. . .	239·9	09·3	73·6	61·2	47·9	36·5
			(*b*) *Jalgaon*			
Mean . .	+917·17	—28·09	—154·04	+32·17	—25·78	—17·91
x'_2 . . .	+474·32	+60·70	—118·85	—64·35	—14·55	+47·75
x'_3 . . .	+616·43	—45·82	—181·62	—6·04	+33·82	+26·13
x'_4 . . .	—342·78	—77·10	+38·52	—20·12	+58·96	+19·77
x'_5 . . .	—393·98	—178·99	—143·84	+74·20	+89·76	—2·85
x'_6 . . .	—237·12	+87·13	+69·06	+48·70	—20·61	—52·87
S. R. . .	267·0	125·0	86·4	67·2	53·5	51·4

For Akola, the mean five-day rainfall does not show any trend over the period of 28 years ; some of the other rainfall distribution constants, however, show tendencies of slow changes. For example, b' shows an upward trend as indicated by its value of x'_2. Significant changes have also occurred in the rainfall distribution constants c' and e' as is seen from the values of x'_3 and x'_6 for c' and of x'_5 for e'. This shows that while the total rainfall at Akola has not changed over the period under consideration, its distribution over the season shows slight changes. The secular changes in the distribution of rainfall at Akola over a period of 65 years has been studied in another paper [Satakopan, 1936].

At Jalgaon the amount of rainfall shows a slight secular change as indicated by the value of x'_3 for the a' constant. The constant c' also shows a similar change.

The series of yields for the two stations were correlated with their respective distribution constants for rainfall to find out the effect of the rainfall and its distribution on the yield. The correlation coefficients after eliminating the secular changes from both the yield and rainfall constant series were determined. These coefficients together with the direct coefficients without eliminating the secular changes are given in Table IV.

TABLE IV

Correlation coefficient of yield with	AKOLA		JALGAON	
	Direct correlation coefficient	Correlation coefficient after eliminating secular trend	Direct correlation coefficient	Correlation coefficient after eliminating secular trend
a'	—0·078	—0·237	—0·292	—0·140
b'	—0·147	—0·341	—0·366	—0·450
c'	0·058	0·138	0·003	0·221
d'	0·082	0·164	0·154	0·162
e'	—0·375	—0·375	0·005	0·024
f'	0·072	0·067	0·190	0·275

It will be seen that the correlation coefficients, though small, have increased in many cases after eliminating the secular trend in the yield and the rainfall distribution constants.

The sums of squares and products of the rainfall distribution constants among themselves, after correcting for the secular changes, are given in Table V. Fisher's method was used to solve the six simultaneous equations to obtain the six coefficients of regression of the rainfall distribution constants on the yield separately for the two stations. In Table VI are given the matrices of multipliers each of which is the co-factor of the corresponding number in Table V divided by the value of the corresponding determinant.

The regression coefficients of the various rainfall constants on the yield are obtained by multiplying the sums of products of yields and the rainfall constants after correcting for the secular changes, by the various figures in the corresponding column of the matrix of multipliers and adding up. The

fegression equations expressing the yields in terms of the distribution constants for the two stations are :

Akola

$$Y^* = -0{\cdot}432\,a' + 0{\cdot}328\,b' \quad -1{\cdot}285\,c' + 1{\cdot}317\,d' \quad -3{\cdot}033\,e' + 2{\cdot}067\,f'$$

Jalgaon

$$Y^* = -0{\cdot}149\,a' + 0{\cdot}191\,b' \quad -0{\cdot}802\,c' + 1{\cdot}573\,d' \quad -1{\cdot}399\,e' + 2{\cdot}178\,f'$$

Though the coefficients have different values it is interesting to note that they have similar signs for the two stations indicating similar relationship in general.

The data for the two stations, as has already been observed, are available only for short periods. They may also be combined to arrive at an estimate of the average relationship of the yield with rainfall in the area which they represent. It is expected that the results, being based on a larger number of observations than is available at one station, will be more reliable, though it must be recognised that the relationship thus deduced will probably be not exactly representative of the situation at either of the two stations. The pooling of the sums of squares and products in Table V together to form a combined regression equation has also a limitation that if there is any extraneous source of variation in yield common to the two stations in one year when the rainfall constants are similar it will introduce an error in the regression formula [Hopkins, 1935].

TABLE V

Sums of squares and products of rainfall distribution constants after correcting for trend

(*a*) *Akola*

a'	+1265938					
b'	+207647	+262798				
c'	—172697	—740	+119196			
d'	—42582	—106029	—26566	+82333		
e'	—11060	—2988	—44938	+7808	+50417	
f'	+14833	+8139	+7332	+26946	+251	+29376

(*b*) *Jalgaon*

a'	+1212281					
b'	+238825	+265595				
c'	—134452	+58305	+126797			
d'	—31634	—34158	—4997	+76742		
e'	—45086	—33013	—41072	+12887	+48717	
f'	—45718	—59804	—16785	—33124	+8481	+44868

*Y, a', b', etc. in the equations represent departures of the respective variables from their polynomial values.

TABLE VI

Matrices of multipliers

a'	b'	c'	d'	e'	f'
			(*a*) *Akola*		
+2·72759	—6·21017	+7·90718	—7·70520	+8·43043	—8·77007
—6·21017	+25·78191	—20·59118	+37·22662	—23·90910	+35·48341
+7·90718	—20·59118	+36·78337	—23·70542	+36·72445	—29·52666
—7·70520	+37·22662	—23·70542	+73·47607	—32·07296	+67·16532
+8·43043	—23·90910	+36·72445	—32·07296	+57·26049	—36·70802
—8·77007	+35·48341	—29·52666	+67·16532	—36·70802	+97·93120
			(*b*) *Jalgaon*		
+1·96645	—3·44389	+4·59228	—2·93743	+4·82221	—3·94872
—3·44389	+21·47110	—10·68097	+29·13231	—13·20264	+45·11634
+4·59228	—10·68097	+22·29350	—10·46298	+20·81640	—12·87640
—2·93743	+29·13231	—10·46298	+64·14781	—23·33652	+83·69135
+4·82221	—13·20264	+20·81640	—23·33652	+45·10136	—30·65014
—3·94872	+45·11634	—12·87640	+83·69135	—30·65014	+141·16104

The combined regression equation obtained was :

$$Y = -0{\cdot}240\,a' \quad -0{\cdot}100\,b' \quad -0{\cdot}856\,c' \quad +0{\cdot}939\,d' \quad -2{\cdot}040\,e' \quad +1{\cdot}447\,f'$$

The values of yields were then calculated for the various years using this regression equation for both stations. These are plotted with their actual values in Fig. 1. Comparatively large differences are observed between the actual and calculated values of yields for the years 1910-11, 1915-16, 1919-20, 1920-21 and 1931-32 at Akola and for 1915-16 and 1917-18 at Jalgaon. The peculiar features of these years are indicated below.*

* The causes of the large deviations of the calculated from the actual values can be grouped under two heads : (*a*) Effects of factors that have not been taken into consideration in evolving the regression equation, *e.g.* November rainfall in 1910-11 at Akola. Heavy rainfall at Akola in November is a comparatively rare phenomenon and hence we have considered only rainfall for the period ending October 23. Unless a long series of records giving many Novembers with varying amounts of rainfall is available it is not possible to express the effect mathematically and include the same in the regression equation. (*b*) Effects due to the inadequate representation of the dependent variate. The mathematical representation of the rainfall distribution by a smooth curve has this natural limitation. We are fitting here a smooth curve to an essentially discontinous variable in point of time. No mathematical function which is continuous can take into

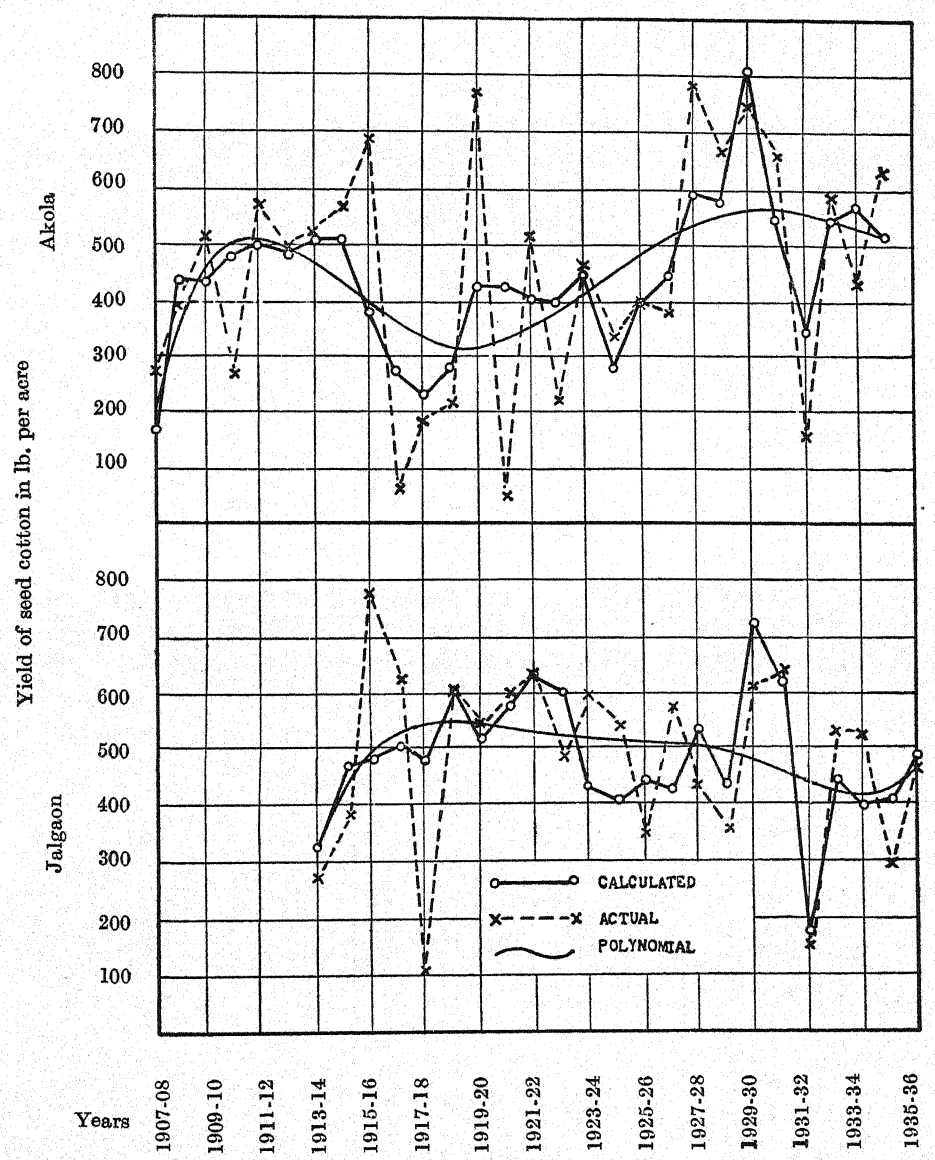


Fig. 1. Calculated and actual yields of seed cotton

consideration all the features of a rainfall distribution. As such, effects such as those observed in the year 1915-16 at Jalgaon remain outside the scope of the regression equation determined.

The purpose of recording these explanations for large departures is that the forecaster who uses the regression equation may, after determining the yield for any year from the equation, modify the value to account for such known effects outside the scope of the equation and give the final forecast.

AKOLA

1910-11.—This year the rains began early and were well distributed throughout the growing season. The first part of the season was very favourable but a fall of rain in the first half of November, a period which is not included in the regression formula, did serious damage to cotton by washing down many of the mature and immature bolls and flowers.

1915-16.—The records at the farm do not show any special notes except that weeding and hoeing operations were taken advantage of fully because of the opportune breaks in the growing season.

1919-20.—This was a remarkable season for the amount of sunshine. There were only 25 rainy days from the 1 July to the end of September and the rainfall was most opportune.

1920-21.—This was an exceptional year. The total rain was only 10·7 in. There was practically no rain for the rest of the cotton season after the first fortnight of July.

1931-32.—The actual yield is even lower than the calculated yield. This may be attributed to the abnormal continuous rain amounting to 9·7 in from 1 to 11 October.

JALGAON

1915-16.—During this year, the rains during the period July 14 to August 6 which would have adversely affected the yield under normal conditions (see response curve) are said to have favoured the crop due to lack of the usual rains up to 14 July. This probably accounts for the high actual yield.

1917-18.—Monsoon broke as late as June 28. Moreover there was hardly sufficient rainfall to keep crops growing till the end of August. Late rains saved the crop from complete ruin.

From the regression coefficients six coefficients expressing the average benefit or loss in lb. per acre ascribable to an additional unit of the distribution constant are determined and these coefficients when combined with the corresponding orthogonal functions of time give a continuous curve showing the average effect in lb. per acre corresponding to an additional inch of rain at any time during the period considered. Such curves which are called ' the response curves ' are given separately for the two stations in Fig. 2 and in a combined form in Fig. 3.

It is interesting to note that there is in general a similarity between the two curves for Akola and Jalgaon except towards the end of the season. Both the stations show an adverse effect for an additional inch of rain in the fourth week of May. Heavy and continuous rainfall in the latter half of July and the first half of August affects the yield adversely as it gives rise to weeds and waterlogging and delays weeding and interculture operations. Heavy rain at the end of September or the early part of October damages the cotton crop by causing the shedding of bolls.

The combined curve confirms the observations recorded above. The adverse effect of rain in the fourth week of May is rather difficult to explain. It may be mentioned that the investigation of the effect of monthly rainfall and temperature on cotton yield in the districts of the Bombay province [Kalamkar, Satakopan and Gopal Rao, 1935] has shown that high average maximum

temperature in May is found to have a beneficial effect on yield in the districts of Khandesh, Surat and Ahmedabad, which may be attributable to the fact that under the influence of the hot sun the black cotton soil ' ploughs itself ', and this exerts a beneficial effect on the subsequent crop of cotton on it.

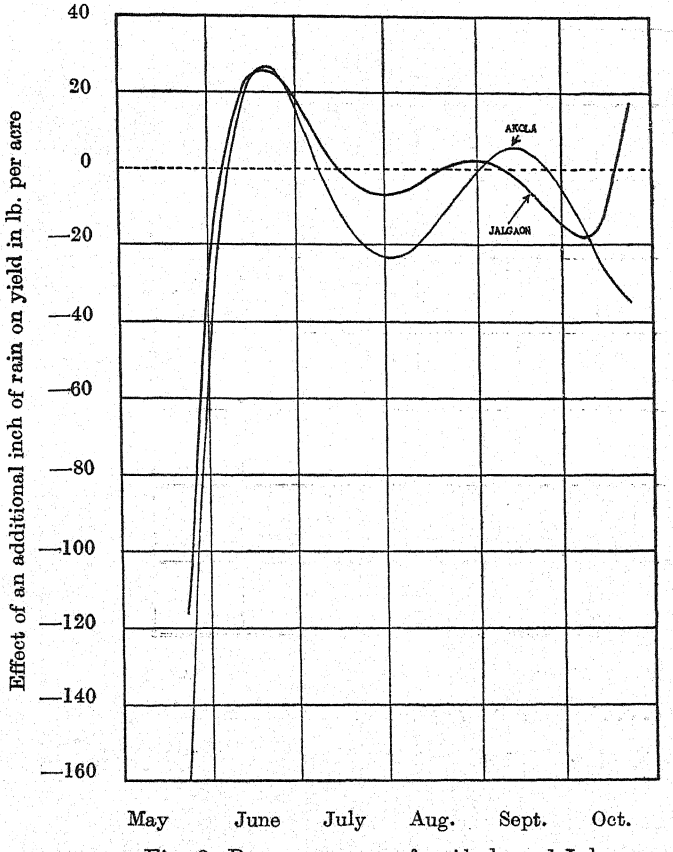


Fig. 2. Response curves for Akola and Jalgaon

Similar adverse effect has been noticed in Gazeira by Crowther [1925] who observes that rainfall in May and June exerts a depressing effect on the yield of cotton sown in the following July or August at Gazeira. He attributes it to the washing off of the nitrates formed in the soil. It may be mentioned in this connection that fortnightly estimations of the total nitrogen in the soil at different depths in the bare plot of the Central Agricultural Meteorological Observatory have been made regularly during the last two-and-a-half years. These data (unpublished) show that the first showers of the season do cause a drop in total nitrogen in the soil. This effect is probably due to leaching. This adverse effect has been also attributed to the possible interference with the soil cracks [Lambart and Crowther, 1935] by rainfall which reduces the rate of drying off of soil and closes the sub-soil cracks, thus preventing adequate sub-soil aeration or water penetration.

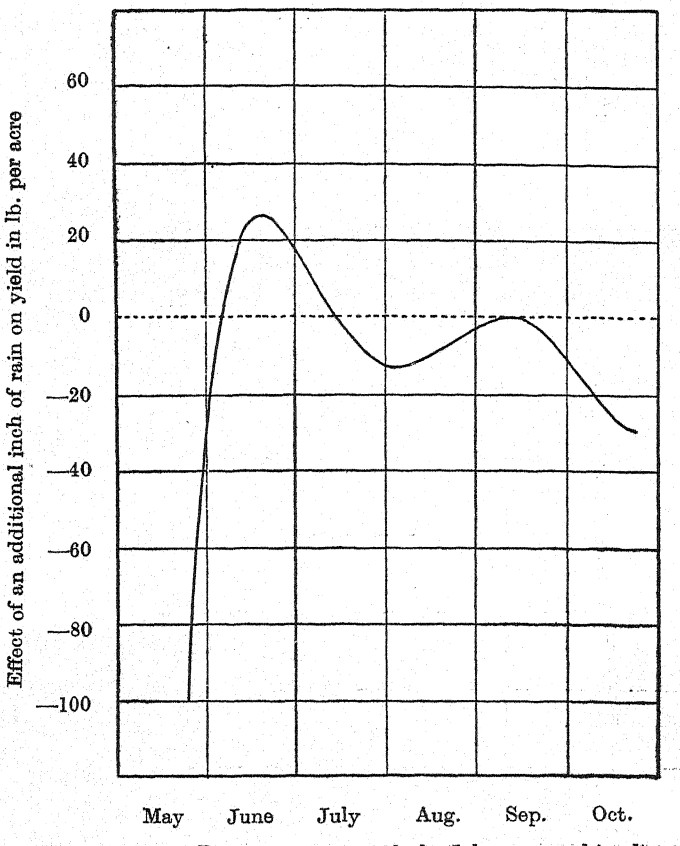


Fig. 3. Response curve (Akola-Jalgaon combined)

Significance of the dependence of yield on the rainfall constants can be tested by partitioning the total sum of squares as indicated in Table VII.

It may be seen that the variances due to regression and the residual do not differ significantly, the multiple correlation coefficients being $R = 0{\cdot}58$ and $R = 0{\cdot}56$ respectively for the two stations. In the analysis of variance for the combined regression, it is seen that the ratio of the mean square due to ' regression ' to that due to ' residual ' is 2·32 which approaches the 5 per cent point for this ratio, *viz.* 2·39 [Snedecor, 1938]. The multiple correlation coefficient is 0·54. It will be observed that the combination of the two series into one equation shows a slight improvement in the significance of the variance due to ' regression ' on account of comparatively larger number of degrees of freedom.

The analysis on the whole indicates that the significance of the rainfall effect is not definitely established from these data at Akola and Jalgaon extending over short periods. It is, however, interesting to note that the response curves showing the average effect in lb. ascribable to an additional inch of rain appears more or less to agree with the usual impressions of the cultivators as regards the influence of rain on the yield of cotton. In this

connection a paper on ' Cotton prospects on the Nagpur Agricultural College Farm ' by McDougal [1935] is of interest.

In conclusion, the authors wish to express their thanks to Dr L. A. Ramdas, Agricultural Meteorologist, Poona, for help in the preparation of this paper.

TABLE VII

Analyses of variance

Factor	D. F.	Sum of squares	Mean square
(*a*) *Akola*			
Regression . . .	6	334,196	55,699
Polynomial . .	5	243,602	48,720
Residual	16	645,451	40,341
Total .	27	1,223,249	45,306
(*b*) *Jalgaon*			
Regression . . .	6	169,082	28,180
Polynomial . . .	5	65,697	13,139
Residual	11	363,246	33,022
Total .	22	598,025	27,183
(*c*) *Akola-Jalgaon (Combined)*			
Regression . . .	6	448,057	74,676
Residual	33	1,063,918	32,240
Total .	39	1,511,975	38,769

REFERENCES

Crowther, E. M. (1925). *Sudan Government Report of a meeting in Gazeira, December 1925*

Fisher, R. A. (1924). *Phil. Trans. Roy. Soc.* (*London*) **B** Series

———— (1925). '*Statistical methods for research workers*' : Oliver and Boyd, London

Hopkins, J. W. (1935). *Canad. J. Res.* **12**, 306-34

Kalamkar, R. J. and Satakopan V. (1935). *Supplements to the Report of the Agricultural Meteorology Branch, India Meteorological Department, for the year ending 21st August 1935*, pp. 1-9

Kalamkar, R. J. ; Satakopan, V. and Gopal Rao, S. (1935). *Supplements to the Report of the Agricultural Meteorology Branch, India Meteorological Department, for the year ending 21st August, 1935*, pp. 41-77

Lambart, and Crowther, F. (1935). *Emp. Expt. Agric. Res.* **3**, No. 12

McDougall, J. C. (1935). *Nagpur Agric. Coll. Mag.* **10**, No. 1

Satakopan, V. (1936). *Ind. Met. Deptt. Sci. Notes* **7**, No. 69

Snedecor, George W. (1938). '*Statistical methods*', pp. 184-7 : Collegiate Press, Inc. Ames., Iowa

THE INHERITANCE OF MEAN FIBRE-LENGTH, FIBRE-WEIGHT PER UNIT LENGTH AND FIBRE-MATURITY OF COTTON

BY

R. S. KOSHAL, M.Sc.

A. N. GULATI, M.Sc.

AND

NAZIR AHMAD, O.B.E., PH.D., F. INST. P.

Indian Central Cotton Committee Technological Laboratory, Matunga, Bombay

(Received for publication on 18 March 1940)

(With one text-figure)

I. INTRODUCTION

THERE are three well-known methods of improving the quality of a crop—(1) importation and subsequent acclimatization of foreign seed, (2) mass or single line selection and (3) hybridization. Of these, the first method appears to have worked fairly well with virgin soils and a few crops, while the other two methods have offered scope for a wider application. Among these, improvement by selection is generally slow but sure in the long run; it has also this quality that if improvement is desired in any one character, it may take place simultaneously in a few other characters which are closely linked to the former. Thus, the improvement by this method is generally all-round, with an especial emphasis on a few closely associated characters. The third method—hybridization—is capable, in theory, of yielding spectacular results, but our knowledge of genetics is so imperfect that examples of such successes are not many in practice. It is, however, possible by employing this method to aim at improvement, by crossing and back-crossing again and again, on a few selected characters. For this purpose, it is necessary that the breeder should have some idea of the degree of inheritance of the character or characters which he wishes to introduce or intensify in a progeny with a view to improving it, and that he should also know the degree of variability of these characters due to seasonal or environmental factors so as to assess the true measure of success achieved by him in his work.

For a crop like cotton, which is grown primarily for industrial purposes, the work of the breeder is intimately connected with that of the technologist, the object of the combined efforts of both being to develop new varieties, which on the one hand, should pay more to the farmers and, on the other, should appeal more to the spinner as compared with the old varieties. The higher monetary return to the grower depends partly upon good yield and ginning percentage and partly upon the superior quality of the cotton, while the spinner is mainly interested in the latter, which should enable him to spin finer or stronger yarns from the new variety. Now, a large number of factors

go to make up what is commonly, and somewhat vaguely, known as the spinning quality of a cotton, but chief among them are the mean fibre-length and fibre-weight per inch, the latter being a measure of its fineness. The relative importance of these two fibre properties, it is interesting to note, is somewhat different for the different groups of cotton. For instance it has been found that for the Egyptian cottons the mean fibre-weight per unit length plays the most important part [Turner, 1934] while for the Indian cottons, the mean fibre-length takes the first place among the factors determining their spinning quality [Turner and Venkataraman, 1934]. Another property which, though not so closely connected with the strength of yarns into which a cotton may be spun, has been found to have an important bearing upon their appearance and neppiness is the maturity of its fibres [Gulati and Ahmad, 1935]. These two fibre properties, namely fibre-weight per inch and maturity, are closely interrelated, as both owe their origin to the deposition of protoplasmic material within the cell-walls during the later half of the development of the fibre. It is, however, noteworthy that while the regular and uninterrupted supply of protoplasm to most of the fibres helps to increase the maturity percentage and, therefore, reduce the neppiness in the yarns, it simultaneously tends to increase the mean fibre-weight per inch, which pulls down the spinning quality of a cotton. Therefore, in order that the yarns spun from the new varieties may combine good strength with a reasonable degree of freedom from neps, the cotton breeder, aided by the technologist, must aim at an improvement in staple length and must also strike a happy balance between fibre-weight per unit length and percentage of mature hairs. It is, therefore, essential that a systematic study should be made of the influence of genetical factors upon these three fibre properties and their response, if any, to environmental factors. But in such studies it is not always easy to separate the environmental from the genetical factors, which are partially masked by the former.

The present investigation provides an example of an experiment in which environmental and genetical factors are combined in a single field experiment, so that the effect of the former can be partially eliminated for the effective study of the latter. The experiment was planned and laid out at the Institute of Plant Industry Farm, Indore. The experimental field of which a plan is shown in Fig. 1 comprised ten randomised blocks each measuring 44 ft. × 24 ft. Each block contained 22 plots, out of which two plots on either side (north and south) were left out as non-experimental areas, leaving 18 plots for the experiment. These 18 plots were distributed as follows :

(1) Parent strains, Cwn 520, Bani and Malvi	3
(2) F_1s, viz. Cwn 520 × Bani, Cwn 520 × Malvi, and Malvi × Bani	3
(3) Four progenies of each F_2	12
	18

Unfortunately the material from the four progenies of F_2s was not available ; consequently we have confined our experiments and discussion to three parent strains and their three F_1s which are marked by slanting and cross lines, respectively, in Fig. 1. Each plot consisted of a single row of plants 24 ft. long ; the plant in the row being 1 ft. apart, while the space between two rows was

2 ft. Two plants on either side (east and west) were discarded so as to allow for border effects, leaving 20 plants per plot for experimental work. Since there were 18 plots in a block, the total number of plants was 360 per block, of which 120 belonged to the three parent strains and their F_1s. If all the plants were studied individually we should have to collect material from, and make the tests on, 1,200 plants. However, material from all the plants was not available. Material from 691 plants (classified as in Table I) was received at the Laboratory for testing.

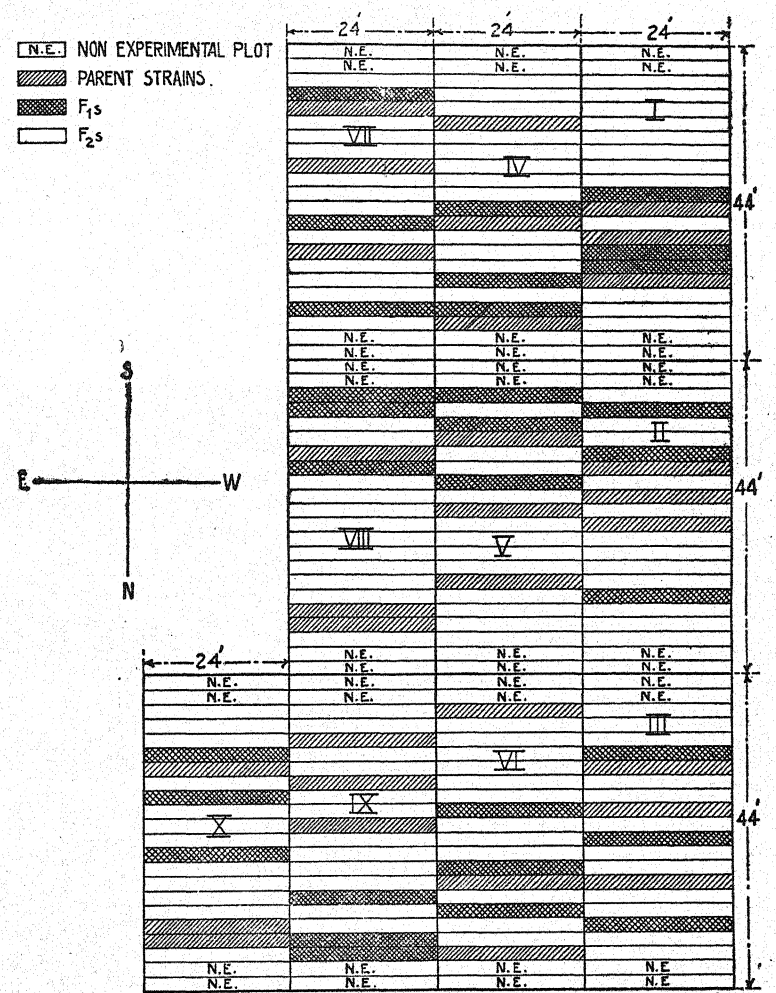


FIG. 1. Sketch plan of experiment 8331/35, I. P. I.

TABLE I

Distribution of samples received for testing

Cotton	Blocks										Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Cwn 520	8	6	12	8	10	13	7	6	7	4	81
Bani	14	15	17	13	16	14	12	8	11	16	136
Malvi	12	11	13	11	9	12	5	13	7	7	100
Cwn 520 × Malvi . . .	11	12	13	16	14	13	11	15	16	13	134
Bani × Malvi	14	11	8	6	10	14	12	14	13	17	119
Cwn 520 × Bani . . .	14	15	10	4	7	9	13	17	19	13	121
	73	70	73	58	66	75	60	73	73	70	691

It will be seen from Table I that the minimum number of plants is four for Cwn 520, block X, and F_1 (Cwn 520 × Bani), block IV ; consequently, if we keep this number as the minimum for all the plots, the total number of plants available for testing would be $4 \times 60 = 240$. We have, however, tested the material from 120 plants, assuming that two plants per plot would be sufficient for the study of plant-to-plant variation. The selection of the material from two different plants out of the total available for each plot (Table I) was made completely at random. Fibre-maturity and fibre-weight per unit length were determined for each of the 120 samples obtained in this way. The measurement of the mean fibre-length and fibre-weight per unit length of these samples was carried out on the new stapling apparatus [Ahmad and Nanjundayya, 1936], while the technique described in an earlier publication [Gulati and Ahmad, 1935] was followed for the maturity count. The results obtained for these 120 samples provide the material for the study of :—

(1) The genetical variation.
(2) Variation between blocks (major environment).
(3) Variation between plots of the same block (minor environment).
(4) Variation between plants of the same plot (environmental and small genetical contribution due to strain impurity).

II. SEPARATION OF ENVIRONMENTAL AND GENETICAL VARIATION

The data obtained for the individual plants for fibre-weight per unit length, percentage of mature hairs, and fibre-length are given in Tables A B and C in the appendix. The environmental and genetical factors are sorted out by the application of analysis of variance. For this purpose we construct sum and difference tables (similar to the split-plot technique) [Koshal, 1935]. The two values given in Table A for each plot are added and this constitutes the sum table (Table II), while their differences form the difference table (Table III). We illustrate this point by reproducing the two tables for fibre-weight per inch, while similar tables were also constructed, but are not reproduced, for the other two properties, namely mean fibre-length and fibre-maturity.

TABLE II

Sum table

(Fibre-weight per unit length)

Cotton \ Blocks	I	II	III	IV	V	VI	VII	VIII	IX	X	Total	
Cwn 520 . . .	5·81	4·86	4·71	4·80	4·82	5·11	4·93	4·60	5·41	4·68	49·73	
Bani . . .	4·44	4·33	4·34	4·81	4·33	4·38	4·44	4·50	4·45	4·32	44·34	145·37
Malvi . . .	5·14	5·02	4·85	5·55	4·90	5·31	4·88	5·14	5·23	5·28	51·30	
Cwn 520 × Malvi . .	5·34	4·95	5·11	4·93	4·36	5·58	4·98	5·19	5·10	5·31	50·85	
Bani × Malvi . .	4·49	4·13	4·89	4·24	4·86	5·23	5·17	4·58	4·76	4·60	46·95	145·59
Cwn 520 × Bani . .	4·50	4·75	5·07	4·61	4·93	4·93	4·92	4·89	4·69	4·50	47·79	
Total .	29·72	28·04	28·97	28·94	28·20	30·54	29·32	28·90	29·64	28·69	290·96	

TABLE III

Difference table

(Fibre-weight per unit length)

Cotton \ Blocks	I	II	III	IV	V	VI	VII	VIII	IX	X
Cwn 520 . .	−0·23	−0·40	−0·15	−0·58	−0·14	0·23	−0·13	0·24	−0·15	−0·58
Bani . .	0·34	0·07	0·04	−0·09	−0·11	−0·62	−0·76	−0·24	0·13	0·42
Malvi . .	0·14	−0·10	0·05	0·01	0·22	0·31	−0·20	−0·20	−0·11	0·42
Cwn 520 × Malvi	−0·16	0·17	−0·65	0·53	0·12	0·04	0·00	0·15	0·28	−0·11
Bani × Malvi .	−0·21	0·09	0·11	−0·26	0·42	0·21	0·39	0·16	−0·36	0·12
Cwn 520 × Bani	−0·42	0·05	0·09	−0·01	0·31	−0·05	0·20	0·09	−0·31	−0·28

The 60 values comprising the sum table are analysed in the usual manner, to separate the effects of varieties, blocks, and plot-to-plot variation, and the 59 degrees of freedom are apportioned as shown in Table IV.

TABLE IV

Preliminary analysis of variance; fibre-weight per unit length

	D. F.	S. S.	M. S.	F	
Varieties . .	5	1·754367	0·350873	8·8687	Significant ($P=0·01$)
Blocks . .	9	0·415170	0·046130	1·1660	Non-significant
Plot error . .	45	1·780350	0·039563		
Total .	59	3·949887			

It will be seen that the variance due to varieties, which includes practically the whole of genetical variation is highly significant, while the variance

due to blocks (environmental) is non-significant. The variation between plants in the same plot can be calculated in two ways :—

(1) The total sum of squares corresponding to 119 degrees of freedom is obtained from the individual plant data of Table A (Appendix) and from this the total sum of squares for 59 degrees of freedom given in Table IV is deducted. The balance will be sum of squares for variations between plants in the same plot, corresponding to 60 degrees of freedom.

(2) The figures given in difference table (Table III) are squared and the resulting sum is divided by 2. This will also provide a check on the calculations.

The complete analysis of variance is given in Table V.

TABLE V

Analysis of variance ; fibre-weight per unit length

	D. F.	S. S.	M. S.	F.	
Varieties	5	1·754367	0·350873	8·6603	Significant for $P = 0·01$
Blocks	9	0·415170	0·046130	1·1386	Non-significant
Plot error	45	1·780350	0·039563 } 0·040515		
Plant error	60	2·473700	0·041228 }		
Total	119	6·423587			

The significance of plot error is judged from the plant error, and since it is non-significant, both can be combined to give 105 degrees of freedom for error. From this analysis it is evident that the evironmental factors (major and minor) are non-significant, and the major portion of the variation, being due to varieties, is of genetical nature.

The results of application of analysis of variance to the data obtained for maturity percentages and mean fibre-length are shown in Tables VI and VII.

TABLE VI

Analysis of variance ; percentage of mature hairs

	D. F.	S. S.	M. S.	F.	
Varieties	5	839·57	167·914	3·624	Significant ($P = 0·01$)
Blocks	9	368·87	40·985	1·026	Non-significant
Plot error	45	2469·43	54·876 } 46·337		
Plant error	60	2396·00	39·933 }		
Total	119	6073·87			

TABLE VII

Analysis of variance ; fibre-length

	D. F.	S. S.	M. S.	F.	
Varieties . .	5	1·89975	0·37995	58·962	Significant ($P=0·01$)
Blocks . .	9	0·11634	0·012927	2·006	Non-significant
Plot error . .	45	0·28998	0·006444	1·804	Significant
Plant error . .	60	0·21425	0·003571		
Total .	119	2·52032			

The relatively small influence of environment on both the fibre-weight per unit length and the mean fibre-length has also been recently pointed out by Barre [1938]. In this experiment 16 varieties of cotton from the same seed stock were grown at 14 different places across the cotton belt in order to study the influence of variety, soil, climate and season on their fibre properties and spinning value. The results of one season indicate that both fibre-weight per unit length and fibre-length are inherited in a definite way, and that the influence of environment is small.

III. GENETICAL VARIATION IN FIBRE-WEIGHT PER UNIT LENGTH, FIBRE-MATURITY AND FIBRE-LENGTH

The total variability with respect to any measureable character may be divided into two classes, (1) Genetic variance, (2) Environmental variance. In a randomised block experiment, such as the one we are discussing, the main environmental effects are equalised between blocks, and the minor effects are distributed at random within blocks. For statistical purposes the various genetical factors may be divided into two parts :—

(*a*) An additive part which reflects the genetic nature without distortion, and

(*b*) the non-additive part which represents the deviation from the direct effects of the different Mendelian factors. This non-additive interaction of the genes is designated as ' epistacy ' by Fisher [1918].

We shall consider in this section the genetical variance in relation to the three fibre properties and the appropriate method for the evaluation of the various genetical factors.

There are three parent strains, Cwn 520, Bani and Malvi. The first question which arises is : Which of these varieties gives the best results on crossing ? If **A**, **B** and **C** represent the set of genes in the parent strains, responsible for fineness, then a comparison* such as

$$(2\mathbf{AA}+\mathbf{AB}+\mathbf{AC})-(2\mathbf{BB}+\mathbf{BC}+\mathbf{AB})$$

* These formulæ were kindly suggested to one of us (R. S. K.) by Prof. R. A. Fisher, F.R.S., during his visit to India (January 1938).

will enable us to find out whether **A** is better than **B** or *vice versa*, while the variance contributed by this factor would be $[(2\mathbf{AA}+\mathbf{AB}+\mathbf{AC})-(2\mathbf{BB}+\mathbf{AB}+\mathbf{BC})]^2 \div 200$. We are now left with the third variety **C** which can be compared with the average effect of **A** and **B**. This is given by

$(4\mathbf{CC}+\mathbf{AC}+\mathbf{BC})-(2\mathbf{AA}+2\mathbf{BB}+2\mathbf{AB})$, while the variance contributed by this factor is given by

$$[(4\mathbf{CC}+\mathbf{AC}+\mathbf{BC})-(2\mathbf{AA}+2\mathbf{BB}+2\mathbf{AB})]^2 \div 600.$$

These two factors may be designated as ' genetic '.

In the present investigation fibre tests were made on 20 plants for each of the three parent strains and their first cross progenies, consequently, **AA**, **BB**, etc. represent the totals of 20 tests. The divisor for calculating the variance due to each factor is obtained by multiplying the sum of squares of the coefficients of **AA**, **BB**, etc. by 20. Thus the figures 200 and 600 are calculated as follows :—

$$(2^2+1+2^2+1)\times 20 = 10\times 20 = 200.$$

$$(4^2+1+1+2^2+2^2+2^2)\times 20 = 30\times 20 = 600.$$

In addition, we can compare the performance of the three parent strains with their F_1s ; this may be done by evaluating the expression

$$\mathbf{AA}+\mathbf{BB}-2\mathbf{AB},$$

i.e., double the value of each cross is compared with the sum of the performance of the two parent lines. If this expression yields a negative result, it is heterosis or hybrid vigour. In some species and in some characters it may happen that these comparisons give predominantly negative results ; in such cases their total contribution constitutes a single comparison for heterosis, or as it is sometime called ' dominance bias.' In the present example this effect is measured by

$$\begin{aligned}&\mathbf{AA}+\mathbf{BB}-2\mathbf{AB}\\ &+\mathbf{AA}+\mathbf{CC}-2\mathbf{AC}\\ &+\mathbf{BB}+\mathbf{CC}-2\mathbf{BC}\end{aligned}$$

and the variance contributed by this factor is obtained by dividing the square of this value by 480.

The figure $480 = 2^2\times 6\times 20$, since the above expression can be put in the form $(2\mathbf{AA}+2\mathbf{BB}+2\mathbf{CC}-2\mathbf{AB}-2\mathbf{AC}-2\mathbf{BC})$

Now the only other genetical factor left is the manner in which interaction takes place between the different genes. This is spoken of as ' epistacy '. The three factors, which contribute to it, are

$$\begin{aligned}&\mathbf{AA}+2\mathbf{BC},\\ &\mathbf{BB}+2\mathbf{AC},\\ &\mathbf{CC}+2\mathbf{AB},\end{aligned}$$

and the sum of squares contributed by the two degrees of freedom corresponding to epistacy are

$$[(\mathbf{AA}+2\mathbf{BC})^2+(\mathbf{BB}+2\mathbf{AC})^2+(\mathbf{CC}+2\mathbf{AB})]^2 \div 100$$
$$-[\mathbf{AA}+\mathbf{BB}+\mathbf{CC}+2\,(\mathbf{AB}+\mathbf{AC}+\mathbf{BC})]^2 \div 300$$

The divisors 100 and 300 are obtained as follows :—

$$(1+2^2)\times 20 = 5\times 20 = 100$$

$$(1+1+1+2^2+2^2+2^2)\times 20 = 15\times 20 = 300$$

We can consequently divide the five degrees of freedom for varieties as shown in Table VIII.

TABLE VIII

Genetical factors ; fibre-weight per unit length

	D. F.	S. S.	M. S.	
Genetic	2	1·697043	0·84852**	Significant ($P=0·01$)
Epistatic	2	0·056920	0·02846	Non-significant
Heterosis	1	0·000404	0·000404	Do.
	5	1·754367		

Thus all the genetical variation is explained by the two degrees of freedom set apart for ' genetic ', the contribution of the other two factors, epistacy and heterosis being entirely non-significant. We shall, therefore, concentrate our attention on this factor only. Since there are three parent strains, the two degrees of freedom can be further broken up into single degrees of freedom in three ways :

	D. F.	Variance	
(*a*) **A** *vs.* **B**	1	1·077512**	Significant ($P=0·01$)
C *vs.* **A** and **B**	1	0·619531**	Significant ($P=0·01$)
Total .		1·697043	
(*b*) **A** *vs.* **C**	1	0·026450	Non-significant
B *vs.* **A** and **C**	1	1·670593**	Significant ($P=0·01$)
Total .		1·697043	
(*c*) **B** *vs.* **C**	1	1·441602**	Significant ($P=0·01$)
A *vs.* **B** and **C**	1	0·255441	Non-significant
Total .		1·697043	

The results show that out of the three varieties Bani not only possesses distinctly lower fibre-weight per unit length, but also its crosses with either of the other two varieties are finer than the other cross. It is further interesting to note that the same conclusions apply to Bani with respect to fibre-length and fibre-maturity. Thus, Bani is the most satisfactory among these three varieties for producing crosses which should combine good staple length with fineness and maturity of hair. As regards the other two cottons analysis shows that there is nothing much to choose between them in this respect.

The analysis of genetical factors for percentage of mature hairs and mean fibre-length is given in Tables IX and X.

TABLE IX

Genetical factors ; percentage of mature hairs

	D. F.	S. S.	M. S.	
Genetic	2	411·01	205·51*	Significant ($P=0·05$)
Epistatic	2	215·23	107·62	Non-significant
Heterosis	1	213·33	213·33*	Significant ($P=0·05$)
		839·57		

TABLE X

Genetical factors, mean fibre-length

	D. F.	S. S.	M. S.	
Genetic	2	1·77064	0·88532**	Significant ($P=0·01$)
Epistatic	2	0·01441	0·00721	Non-significant
Heterosis	1	0·11470	0·11470**	Significant ($P=0·01$)
		1·89975		

It will be noticed that both for fibre-maturity and length, in addition to genetic comparison, heterosis is also significant, showing that the hybrids possess a tendency to produce fibres which are on the average maturer and longer than those in the parent strains. It is interesting to note that for all the three fibre properties studied in this investigation the effect of epistacy is small and non-significant. We may, therefore, conclude that the major portion of genetic variation is capable of being explained by the direct additive effect of the genes.

IV. FURTHER STUDY OF HETEROSIS

In the preceding section we found definite evidence for the existence of heterosis with respect to percentage of mature hairs and fibre-length. We shall now study this point in greater detail. If we represent the three parent strains, Malvi, Bani and Cwn 520 by M, B and C, we can denote the various crosses as under :—

Cross	Symbol
Malvi × Bani	$F_{1\ M\times B}$
Cwn 520 × Malvi	$F_{1\ C\times M}$
Cwn 520 × Bani	$F_{1\ C\times B}$

The average of the two parent strains may be indicated as A ; thus $A_{M\times B}$ with respect to any character would represent the average value of the two parent strains M and B.

Now, when two parent strains are crossed, there are in general three possibilities with respect to any measurable character :—

(1) The hybrid may be greater than the lower parent, but lower than the average of the two parents.

(2) It may be greater than the average of the two parents, but lower than the higher parent.

(3) It may be greater than either of the two parents. The last case is generally spoken of as heterosis or hybrid vigour.

Comparisons made along the lines indicated above are given in Tables XI and XII. We will first consider fibre-maturity.

TABLE XI

Heterosis in fibre-maturity

Malvi × Bani	F_1 M×B—M	$=2\cdot7\pm2\cdot15$	Non-significant
	F_1 M×B—B	$=-0\cdot7\pm2\cdot15$	Non-significant
	F_1 M×B—A M×B	$=1\cdot0\pm1\cdot86$	Non-significant
Cwn 520 × Bani	F_1 C×B—B	$=3\cdot2\pm2\cdot15$	Non-significant
	F_1 C×B—C	$=8\cdot2\pm2\cdot15$	Significant
	F_1 C×B—A C×B	$=5\cdot7\pm1\cdot86$	Significant
Cwn 520×Malvi	F_1 C×M—M	$=0\cdot06\pm2\cdot15$	Non-significant
	F_1 C×M—C	$=2\cdot2\pm2\cdot15$	Non-significant
	F_1 C× —A C×M	$=1\cdot4\pm1\cdot86$	Non-significant

We obtain some interesting results from Table XI. When Malvi and Cwn 520 are each crossed with Bani, we get two F_1 s. Of these, F_1 M×B gives a higher percentage of mature hairs than the average of the two strains, but the increment is non-significant. On the other hand, the cross F_1 C×B gives a higher percentage of mature hairs than either of the two parents, but the increase over the higher parent is non-significant.

The third cross F_1 C×B, like F_1 M×B, is not significantly different from the average of the two parent strains in respect of fibre-maturity. Thus, the average heterosis described in the previous section is due mainly to the cross between Cwn 520 and Bani. The same conclusion is obtained if we adopt the more general definition of heterosis and measure it by comparing twice the value of each cross with the sum of the values for the two parent lines.

We will now consider mean fibre-length.

TABLE XII

Heterosis in mean fibre-length

Malvi×Bani	F_1 M×B—M	$=0\cdot22\pm0\cdot025$	Significant
	F_1 M×B—B	$=-0\cdot04\pm0\cdot025$	Non-significant
	F_1 M×B—A M×B	$=-0\cdot09\pm0\cdot022$	Significant
Cwn 520×Bani	F_1 C×B—B	$=-0\cdot13\pm0\cdot025$	Significant
	F_1 C×B—C	$=0\cdot22\pm0\cdot025$	Significant
	F_1 C×B—A C×B	$=0\cdot04\pm0\cdot022$	Non-significant
Cwn 520×Malvi	F_1 C×M—M	$=0\cdot01\pm0\cdot025$	Non-significant
	F_1 C×M—C	$=0\cdot10\pm0\cdot025$	Significant
	F_1 C×M—A C×M	$=0\cdot06\pm0\cdot022$	Significant

It will be seen from Table XII that none of the crosses gives significantly higher length than both the parent strains, though in each case the cross is significantly longer than the lower parent, while in two cases, namely F_1 M×B and F_1 C×M the mean length of the cross is not significantly different from that of the higher parent. There is thus evidence of a pooling of hereditary factors with the result that the combined effect is better than that which either can produce alone. This is confirmed by calculating heterosis from the general equation involving both the parent lines :—

M+B—2 F_1 M×B	=—0·086±0·018	Significant
B+C—2 F_1 B×C	=—0·046±0·018	Significant
M+C—2 F_1 M×C	=—0·053±0·018	Significant

Thus all the three crosses show evidence of hybrid vigour although it is more pronounced for the two crosses, F_1 M×B and F_1 M×C, for which the negative differences are significant even for one per cent point.

V. Inter-relation of fibre-weight, fibre-maturity and fibre-length

Table XIII shows the result of applying analysis of variance and covariance to the three fibre properties studied in this investigation with a view to finding out the inter-relationship between them.

Table XIII

Inter-relationship between fibre-weight, fibre-maturity and fibre-length

	D. F.	r_{mw}	r_{ml}	r_{lw}
Varieties	4	—0·6092	0·7313	—0·8829*
Blocks	8	—0·1772	—0·1298	—0·2179
Plot-to-plot	44	0·4624**	0·1861	—0·3531*
Plant-to-plant	59	0·5198**	0·2689	—0·1096

The following conclusions are drawn from Table XIII :—

(*1*) *Between fibre-maturity and fibre-weight.*—The correlation between plants within the same plot is highly significant, indicating that, regardless of any variety, samples with high fibre-maturity are usually associated with high fibre-weight per unit length or, in other words, mature fibres are generally coarser for all varieties of cotton. The correlation is +0·520, which agrees fairly well with the value +0·595 found by Gulati and Ahmad [1935] for the 32 Indian cottons studied by them.

(*2*) *Between fibre-length and fibre-weight.*—The correlation for varieties is significant, i.e. cottons having long staple usually have low fibre-weight per unit length. This relationship, however, need not necessarily hold good for strains belonging to the same variety, for when the effect of varieties is removed, the correlation −0·1096 for plants within the same plot is small and non-significant. This shows the existence of differential response among different varieties in this respect. This confirms the results of an earlier

investigation on cottons of different botanical species carried by Iyengar and Turner [1930]. They found that while among the *hirsutum* cottons, fibres of longer length generally possessed low fibre-weight per inch, the fibres of *herbaceum, neglectum* and *indicum* cottons do not generally show any such change of fibre-weight with fibre-length.

Summary

This paper describes the results of an investigation undertaken with the object of studying the inheritance of three fibre properties, namely mean fibre-length, fibre-weight per unit length and fibre-maturity, which are known to have a considerable effect on the quality of yarn spun from a cotton. The tests were made on samples of three parent strans, namely Cwn 520, Bani and Malvi and their F_1s grown in a randomised block experiment in the same year at the Institute of Plant Industry, Indore.

From the preliminary analysis of variance it is found that the major portion of the observed variation is due to varieties and is of genetical nature, the variance due to blocks being small and non-significant. In order to study this genetical variation in greater detail, the variance for varieties was split up into three parts representing (1) genetic, (2) epistacy and (3) heterosis. Further analysis showed that for fibre-weight per unit length, greater part of the variation is of genetic origin, the effect of other two factors—epistacy and heterosis—being non-significant. For fibre-maturity and fibre-length, however, heterosis, in addition to genetic comparisons, is also found to be significant, showing that the hybrids possess the tendency to produce, on the average, larger number of mature and longer fibres than the parent strains. Further study of heterosis indicated that the cross Cwn 520 × Bani gave significantly higher maturity than the mean of the parents, while in the other two crosses, although the maturity values were higher than the mean of the two parents the differences were not significant. As against it, all the hybrids showed that there is evidence of the existence of heterosis in fibre-length, for each one of them gave significantly higher mean fibre-length than the mean of the two parents.

In order to find out which variety gives the best results on crossing, a comparison study was made for the parents and their first cross progenies. If **A**, **B** and **C** represent a set of genes, characteristic of the parent strains, in respect of any one fibre character, the expression

$$(2\mathbf{AA} + \mathbf{AB} + \mathbf{AC}) - (2\mathbf{BB} + \mathbf{BC} + \mathbf{AB})$$

would enable us to say whether or not **A** is better than **B**. On applying this method to the three fibre properties it was found that Bani gave significantly higher fibre-length and fibre-maturity, and lower fibre-weight than the other two varieties. Among the two crosses of Bani, the one with Malvi is longer and finer than that with Cwn 520. It is suggested that Bani should be crossed with other suitable varieties to find out where the shuffling of useful characters occurs to the best advantage for the improvement of quality.

By the application of analysis of covariance two interesting correlations which confirm the previous findings were obtained :—

(*1*) *Correlation between fibre-maturity and fibre-weight.*—The correlation for plants within the same plot is positive and significant, indicating that, regardless of any variety, mature fibres are generally coarser.

(2) *Correlation between fibre-length and fibre-weight per unit length.*— The correlation for varieties is negative and significant, but for plants within the same plot, it is non-significant. This shows that fibres of longer length of all cottons do not generally give less fibre-weight per unit length, indicating that a differential response may exist among varieties in this respect.

REFERENCES

Turner, A. J. (1934). *Emp. Cotton Grow. Rev.* **11**, 10-24

Turner, A. J. and Venkataraman, V. (1934). *J. Text. Inst.* **25**, TI-T47

Gulati, A. N. and Ahmad, N. (1935). *J. Text. Inst.* **26**, T261-T292

Ahmad N. and Nanjundayya, C. (1936). *Ind. Cent. Cotton Comm. Tech. Bull. Series B, No.* **21** (or *J. Text. Inst.* **27**, T253-T272)

Ahmad, N. and Gulati, A. N. (1936). *J. Text. Inst.* **27**, T109-T111

Koshal R. S. (1935). *Proc. First Conf. of Crop and Soil Wing of the Board of Agriculture in India, 1935*, pp. 176-89

Barre, H. W. (1938). *Internat. Cot. Bull.* **16**, 521-2

Fisher, R. A. (1918). *Trans. Roy. Soc. (Edin.)*, p. 404

Iyengar, R. L. N. and Turner, A. J. (1930). *Ind. Cent. Cotton Comm. Tech. Bull. Series B.* No. **7** (or *J. Text. Inst.* **21**, T417-T440)

APPENDIX

EXPERIMENTAL DATA FOR THE THREE FIBRE-PROPERTIES

TABLE A

Fibre-weight per unit length (10^{-6} $\frac{gm.}{cm.}$)

Blocks / Varieties	I	II	III	IV	V	VI	VII	VIII	IX	X
Cwn 520	*840-12* 2·79	*840-10* 2·23	*840-7* 2·28	*840-1* 2·11	*840-3* 2·34	*840-4* 2·67	*840-4* 2·40	*840-7* 2·42	*840-3* 2·63	*840-13* 2·05
	840-18 3·02	*840-17* 2·63	*840-15* 2·43	*840-9* 2·69	*840-8* 2·48	*840-16* 2·44	*840-12* 2·53	*840-19* 2·18	*840-12* 2·78	*840-18* 2·63
Bani	*838-2* 2·39	*838-6* 2·20	*839-10* 2·19	*838-2* 2·36	*838-3* 2·11	*838-1* 1·88	*839-11* 1·84	*839-3* 2·13	*839-15* 2·29	*839-3* 2·37
	838-10 2·05	*838-16* 2·13	*839-20* 2·15	*838-10* 2·45	*838-13* 2·22	*838-13* 2·50	*839-14* 2·60	*839-19* 2·37	*839-17* 2·16	*839-8* 1·95
Malvi	*835-4* 2·64	*836-14* 2·46	*835-9* 2·45	*835-5* 2·78	*837-7* 2·56	*835-1* 2·81	*835-11* 2·34	*837-1* 2·47	*835-5* 2·56	*836-6* 2·85
	835-5 2·50	*836-20* 2·56	*835-12* 2·40	*835-16* 2·77	*837-14* 2·34	*835-11* 2·50	*835-17* 2·54	*837-6* 2·67	*835-18* 2·67	*836-10* 2·43
Cwn 520 × Malvi	*860-7* 2·59	*856-11* 2·56	*858-6* 2·23	*855-2* 2·73	*854-8* 2·24	*852-3* 2·81	*857-9* 2·49	*851-6* 2·67	*853-1* 2·69	*859-4* 2·60
	860-10 2·75	*856-13* 2·39	*858-11* 2·88	*855-8* 2·20	*854-18* 2·12	*852-9* 2·77	*857-15* 2·49	*851-14* 2·52	*853-17* 2·41	*859-9* 2·71
Bani × Malvi	*862-6* 2·14	*867-12* 2·11	*866-11* 2·50	*861-4* 1·99	*869-8* 2·64	*870-2* 2·72	*868-4* 2·78	*865-14* 2·37	*863-14* 2·20	*864-2* 2·36
	862-9 2·35	*867-17* 2·02	*866-13* 2·39	*861-20* 2·25	*869-18* 2·22	*870-13* 2·51	*868-16* 2·39	*865-18* 2·21	*863-19* 2·56	*864-20* 2·24
Cwn 520 × Bani	*847-1* 2·04	*849-17* 2·40	*845-16* 2·58	*842-5* 2·30	*848-7* 2·62	*850-5* 2·44	*841-2* 2·56	*844-3* 2·49	*846-7* 2·19	*843-5* 2·11
	847-11 2·46	*849-19* 2·35	*845-19* 2·49	*842-15* 2·31	*848-19* 2·31	*850-20* 2·49	*841-13* 2·36	*844-6* 2·40	*846-8* 2·50	*843-15* 2·39

Figures in *italics* indicate the progeny and plant number

TABLE B

Percentage of mature hairs

Blocks / Varieties	I	II	III	IV	V	VI	VII	VIII	IX	X
Cwn 520 . .	*840-12* 80 *840-18* 79	*840-10* 63 *840-17* 63	*840-7* 67 *840-15* 62	*840-1* 41 *840-9* 66	*840-3* 72 *840-8* 70	*840-4* 76 *840-16* 66	*840-4* 75 *840-12* 71	*840-7* 61 *840-19* 60	*840-3* 74 *840-12* 77	*840-13* 54 *840-18* 75
Bani . .	*838-7* 78 *838-10* 74	*838-6* 75 *838-16* 71	*839-10* 73 *839-20* 69	*838-9* 77 *838-10* 85	*832-3* 74 *838-13* 77	*838-1* 75 *838-13* 60	*839-11* 49 *839-14* 68	*839-3* 70 *839-19* 79	*839-15* 81 *839-17* 80	*839-3* 72 *839-8* 65
Malvi . .	*835-4* 69 *835-5* 67	*836-14* 61 *836-20* 72	*835-9* 68 *835-12* 58	*835-5* 65 *835-16* 77	*837-7* 79 *837-14* 71	*835-1* 68 *835-11* 70	*835-11* 60 *835-17* 69	*837-1* 77 *837-6* 73	*835-5* 72 *835-18* 67	*836-6* 76 *836-10* 65
Cwn 520 × Malvi	*860-7* 69 *860-10* 60	*856-11* 66 *856-13* 68	*858-6* 75 *858-11* 69	*855-2* 74 *855-8* 63	*854-8* 78 *854-18* 68	*852-3* 78 *852-9* 67	*857-9* 58 *857-15* 72	*851-6* 74 *851-14* 72	*853-1* 70 *853-17* 70	*859-4* 71 *859-9* 74
Bani × Malvi .	*862-6* 71 *862-9* 76	*867-12* 73 *867-17* 76	*866-11* 71 *866-13* 72	*861-4* 64 *861-20* 72	*869-8* 75 *869-18* 67	*870-2* 70 *870-13* 75	*868-4* 72 *868-16* 67	*865-14* 73 *865-18* 72	*863-14* 70 *863-19* 74	*864-2* 73 *864-20* 74
Cwn 520 × Bani	*847-1* 64 *847-11* 78	*849-17* 85 *849-19* 80	*845-16* 84 *845-19* 80	*842-5* 76 *842-15* 66	*848-7* 87 *848-19* 68	*850-5* 67 *850-20* 70	*841-2* 86 *841-13* 70	*844-3* 79 *844-6* 71	*846-7* 69 *846-8* 80	*843-5* 77 *843-15* 78

Figures in *italics* indicate the progeny and plant number

TABLE C

Fibre-length (cm.)

Blocks / Varieties	I	II	III	IV	V	VI	VII	VIII	IX	X
Cwn 520 . .	*840-12* 1·62 *840-18* 1·60	*840-10* 1·74 *840-17* 1·77	*840-7* 1·68 *840-15* 1·71	*840-1* 1·60 *840-9* 1·72	*840-3* 1·68 *840-8* 1·64	*840-4* 1·75 *840-16* 1·68	*840-4* 1·79 *840-12* 1·80	*840-7* 1·77 *840-19* 1·74	*840-3* 1·71 *840-12* 1·74	*840-13* 1·72 *840-18* 1·75
Bani . .	*838-2* 2·10 *838-10* 2·08	*838-6* 2·06 *838-16* 2·19	*839-10* 2·14 *839-20* 2·06	*838-2* 2·09 *838-10* 2·06	*838-3* 2·05 *838-13* 2·04	*838-1* 2·17 *838-13* 2·04	*839-11* 1·94 *839-14* 1·98	*839-3* 2·03 *839-19* 1·99	*839-15* 2·14 *839-17* 1·95	*839-3* 2·07 *839-8* 2·08
Malvi . .	*835-4* 1·78 *835-5* 1·66	*836-14* 1·71 *836-20* 1·81	*835-9* 1·82 *835-12* 1·69	*835-5* 1·72 *835-16* 1·81	*837-7* 1·87 *837-14* 1·91	*835-1* 1·76 *835-11* 1·86	*835-11* 1·88 *835-17* 1·84	*837-1* 1·89 *837-6* 1·90	*835-5* 1·76 *835-18* 1·85	*836-6* 1·73 *836-10* 1·75
Cwn 520 × Malvi	*860-7* 1·67 *860-10* 1·69	*856-11* 1·74 *856-13* 1·88	*858-6* 1·92 *858-11* 1·70	*855-2* 1·80 *855-8* 1·87	*854-8* 1·91 *854-18* 1·89	*852-3* 1·79 *852-9* 1·82	*857-9* 1·83 *859-15* 1·83	*851-6* 1·89 *851-14* 1·88	*853-1* 1·78 *853-17* 1·82	*859-4* 1·78 *859-9* 1·68
Bani × Malvi .	*862-6* 1·94 *862-9* 1·97	*867-12* 2·00 *867-17* 2·13	*866-11* 2·03 *866-13* 2·01	*861-4* 1·99 *861-20* 2·00	*869-8* 2·05 *869-18* 2·01	*870-2* 1·89 *870-13* 2·01	*868-4* 2·09 *868-16* 2·02	*865-14* 2·00 *865-18* 2·15	*863-14* 2·08 *863-19* 1·91	*864-2* 2·07 *864-20* 2·00
Cwn 520 × Bani	*847-1* 1·82 *847-11* 1·85	*849-17* 1·97 *849-19* 1·94	*845-16* 1·91 *845-19* 1·78	*842-5* 1·94 *842-15* 1·84	*848-7* 1·74 *848-19* 1·85	*850-5* 2·02 *850-20* 2·00	*841-2* 2·01 *841-13* 1·97	*844-3* 2·05 *844-6* 1·94	*846-7* 1·98 *846-8* 2·02	*843-5* 1·96 *843-15* 2·07

Figures in *italics* indicate the progeny and plant number

STUDIES ON KUMAUN HILL SOILS *

I. SOIL SURVEY AT THE GOVERNMENT ORCHARD, CHAUBATTIA: FORMATION OF GENETIC GROUPS

BY

B. K. MUKERJI, PH.D., D.SC.

Agricultural Chemist to Government, United Provinces

AND

N. K. DAS, M.SC., ASSOC. I.A.R.I.

Research Assistant Soil Chemist

(Received for publication on 6 February 1940)

(With Plate XLV)

I. GENERAL

THE Hills of Kumaun division forming a part of the southern outer spurs of the Himalayas comprise three districts of the United Provinces—Almora, Garhwal and Naini Tal. Beginning from the snowy range, this division consists of a succession of ridges of decreasing heights southwardly. These hills contain very little level land. Cereal crops are cultivated on terraced hill slopes, particularly where factors such as height, situation and irrigation facilities are favourable. In addition to these crops, the suitability of some of the tracts for fruit cultivation has been established with the result that a very large number of fruit orchards have developed in recent years on commercial lines for temperate fruits like apples, pears, peaches, cherries, plums, strawberries, etc. No quantitative data are, however, available on the suitability of the different types of hill soils for different fruit trees, nor are there any quantitative data correlating the soil conditions with the incidence of diseases and pests. The importance of knowing the soils intimately is felt all the more as, these hill soils being mostly primary in origin, a knowledge of the nature of the major soil-forming processes and development of the diverse soil types is a feature of fundamental importance to the fruit growers of these hills.

In India, no systematic work on hill soils, specially from a pedogenic point of view, has been reported so far. The work reported by Mann [1933] on the tea soils of Assam hills was merely an analytical evaluation of those soils in regard to their crop-bearing capacity. The applied science of pedology is still in its infancy in India. Credit must therefore go to Basu and Sirur [1938] for the first and the most systematic pedogenic study of the canal soils of Bombay. Pedological studies for the mountain soils in other countries too have not been at all as numerous as for plain soils. Zokharov [1927] in his

* The researches forming the subject matter of this publication were carried out in the Soil Chemistry Section at Chaubattia (Kumaun) under the Hill Fruit Research Scheme financed by the Imperial Council of Agricultural Research (India).

remarkable treatise on pedology was the first to recognize the following four types of soil formations in the mountains : Mountain steppe, mountain forest, mountain meadow and mountain tundra soils. Mountain forest soils which are of interest to us were divided into four groups, depending on the colour of the soils. But analytical figures revealed that the differences were not fundamental, and all the groups were podsolic. Various other investigations, notably by Neustruev [1915], Akimzev [1930] and Throp [1931], have dealt with the vertical zonality of the mountain soils as the counterpart of the horizontal zonality of the soils in the plains. Alpine soils discussed by Jenny [1930] fit in well with Zokharov's mountain meadow soils. Besides these, considerable information is available on the general nature of the mountain soils.

The investigations reported by Jenny [1926], Vilenski [1930], Robinson and Wasowicz [1935], to name only a few, illustrate the development of mountain soils under varied conditions. Jenny [1926] has observed that 80 per cent of alpine soils developed on calcareous material are acidic. It is clear that although the general nature of hill soils is known, a detailed knowledge of the soil-forming processes and soil types under various topographical and geological conditions have not yet been thoroughly investigated. For instance it has been shown by Kellog [1936] that local soil variations may be considerable within the region of a particular soil zone in the plains, but this question has not however been investigated with reference to the hill soils.

In India and elsewhere hill soils have been studied in some detail from erosion point of view. But in most cases these investigations have been directed to elucidate the relationship between erodibility and forest vegetation. It is only in the U. S. A. that attempts are being made to study soil profiles in their relation to erodibility. In India considerable work, particularly in connection with afforestation policy and controlled grazing [Gorrie, 1937], has been done in the hills, but the nature of hill soils from the point of view of erodibility has nowhere been investigated. The observations made in the U. S. A. by Bennett [1926], Middleton [1932], Baver [1933], Lutz [1934] and Bouyoucos [1935] make it clear that the soil properties, such as structure, texture, plasticity, etc. are directly responsible for the high erodibility of some soils ; whereas Lowdermilk [1930] and Miller [1931] associate erodibility with definite soil types. The advantage of terracing hill slopes to decrease run-off and conserve soil moisture [Ramser, 1933] have been indicated ; but whether topographically immature hill soils, particularly those situated along steep slopes, can be profitably utilized by terracing have not been thoroughly investigated.

To elucidate these points a detailed soil survey of the Government Orchard at Chaubattia was thought to be highly desirable. Accordingly a scheme of survey was taken up about six years ago with the double object of :

(*i*) Studying the relationship between soil conditions and differential behaviour of various fruit trees, stock and varieties with a view to be able to advise with confidence the commercial orchardists of Kumaun on the planting of new orchards, or, if necessary, relaying of old orchards ; and (*ii*) ascertaining whether there is any clear-cut relationship between soil conditions and the incidence of diseases and pests.

The present contribution aims at recording the formation of soils at Chaubattia under unterraced natural conditions. Chaubattia is situated at 29½° N. Latitude and 79½° E. Longitude and the height above sea-level varies from 6,100 ft. to 6,900 ft. The soils studied lie on the northern face of the Chaubattia hills overlooking the distant perpetual snow-topped Himalayan ranges of Nanda Devi, Trisul and Nanda Kud.

TABLE I

Monthly weather record at Chaubattia

Month	Temperature (°F.)		Humidity per cent at 8 A.M.	Rainfall (in.)
	Maximum	Minimum		
January	49·35	37·42	87	4·64
February	50·56	37·32	83	3·56
March	65·25	49·58	55	0·08
April	74·18	56·83	49	0·08
May	76·90	70·22	69	1·82
June	72·88	61·00	81	11·40
July	71·52	62·00	98	19·38
August	72·13	61·42	95	14·50
September	73·00	58·76	91	1·22
October	68·96	53·28	76	0·40
November	59·30	42·57	76	..
December	59·34	42·90	79	..
		Total annual rainfall		57·08

HISTORY OF CHAUBATTIA

The Government Orchard at Chaubattia was started in the year 1870 with about 40 acres of land given to the growing of temperate fruits. Subsequently more lands were brought under cultivation and at present it consists of a cultivated area of 100 acres. The hill slopes for the greater part of the orchard have been terraced. Contour planting has been done in certain parts of the orchard after clearing the forest lands about the year 1924. The present contribution deals with this part of the orchard, where pedogenic processes have not been distorted by terracing operations. These slopes are always under grasses, and fruit cultivation is done by contour planting.

TABLE II

Soil temperature—monthly averages (soil type—brownish loam)

Month	Temperature (°C.)		
	4 in. depth	6 in. depth	12 in. depth
January	4·52	5·38	6·77
February	4·70	5·56	6·67
March	10·75	11·65	12·31
April	16·65	17·45	18·01
May	13·05	20·20	21·05
June	19·04	19·73	20·69
July	16·14	19·83	20·33
August	19·48	20·00	20·50
September	18·13	18·87	20·28
October	14·98	16·02	18·20
November	9·68	10·73	13·20
December	7·58	8·15	10·41

CLIMATE

No systematic meteorological records of Chaubattia are available prior to the year 1935. The records of maximum and minimum temperatures, humidity and rainfall for 1938, supposed to be one of the normal years, are given in Table I. Winter rains, accompanied sometimes with snow, are usually confined to the months of January and February. There are about two to three snow-falls every year and in some years rains start early in the month of December. The months of March, April, May, October and November are usually rainless. *Chota barsat* (local rainfall) in May heralds the advent of monsoon a month earlier, and July and August are the wettest months in the year. It is usual to find frost every morning from November till the middle of February, and in shady places a thick matting of this remains throughout the winter months. The maximum temperature of 85°F. is recorded in the month of May with a minimum temperature of 23°F. in the month of January. There are two rises every year in maximum temperatures. The highest rise is recorded before the monsoon and the second rise takes place after this

sometime in September. There are similarly two rises in soil temperatures before and after the monsoon.

During the monsoon, although the temperature of the sub-soil at a depth of one foot remains fairly constant, the surface soil experiences some minor fluctuations. With the advent of frost in the month of November the soil temperature goes down considerably and snow and rain keep the temperature at a low level till the end of February. The trend of the average soil temperatures at different depths will be clear from Table II.

Grass vegetation along hill slopes gets fully established after the light shower (*chota barsat*) in May and consequently the worst effect of heavy monsoonic downpour in July and August, sometimes 6 in. in a single day, are partly counteracted. This natural agency is not to a small degree responsible for the preservation of soil in these hill slopes in spite of intensive land utilization practices. But along steep slopes extremely deep erosion gullies have been formed on account of the indiscriminate destruction of forests for agricultural purposes. The southern slopes of these hills are on the average warmer, where some of the typical tropical plants like mangoes, guavas, etc. are grown with success.

VEGETATION

The forest vegetation of the locality chiefly consists of different species of *Quercus* (oaks) and *Pinus longifolia*. The oak prefers a humid locality of undulating type, not very steep, while the pine thrives best in dry localities and grows even on mantle rock surfaces. Among the minor forest arboreal flora, mention may be made of the following: *Rhododendron arboreum* (Smith), *Pieris ovallfolia* (Don.), *Myrica sapids*, *Pyrus pashia* (B.Ham.), *Prunus puddum* (Roxb.), *Aesculus hippocastanum*, *Cedrus deodara* and *Cupressus* sp.

The undergrowth which is mostly confined to oak forest mainly consists of different species of the following genera :—*Rhubus*, *Cratagus*, *Herberis Daphne*, *Rosa moschata* (Mill), *Indigo-fera*, *Vibernum* and *Myrsine africana* L. There is very little, if any, undergrowth of importance under pine forest. Probably this is the reason for the local belief that an ideal site for an orchard is the locality where oak predominates and the site of a pine forest should be avoided as far as possible. It has been found that the depth of soil in a predominantly pine forest hardly reaches a foot, whereas brown and podsolic soil formations are usually met with in the oak forests.

The grasses and weeds met with in cleared forest lands belong to the following groups :—*Imperata cylindrica*, *Oenothera biennis*, *Oenothera rosea* (Sim.), *Oxalis* sp., *Imperata arundinacea* (Cyrill), *Paspalum* sp., *Andropogon contortus* L., *Cetraria glauca* (bean), *Ranunculus diffusus* (in the valleys), *Andropogon mycranthus* (Kuth), *Arundinella setosa* (Trin.), *Anthistriia anathera* (Nees).

It is interesting to note how each of these different species occurs under different soil conditions,. *Saccharum spontaneum* (*kans*) and *Imperata cylindrica* (*siroo*) usually prefer a soil containing little or no organic matter and with very loose sub-soil consistency. Therefore they are mostly found growing on ridges and seldom in lowlands. On the other hand, *Rhubus*, *Ranunculus*, *Ophiopogon*, *Pteris* (Bracken), *Reinwardtis*, *Berberis* and *Polygonum* prefer organic moist soils and shady places.

GEOLOGY

There are two main soil-forming rocks of importance in this locality, viz. garnetiferous biotite-schist and weathered granite gneiss*. Although on an average the analytical figures for these two types of rocks are not very different, the nature of the overlying soils, formed under more or less identical condition, is very dissimilar. Under the local conditions biotite as a parent material invariably produces heavier-textured soils than granite gneiss ; the former is by far more easily influenced by soil genetic processes, as is evident from the fact that in the zones where both of these rocks occur together biotite appears to be considerably more disintegrated than granite. The weathered product of the former is sticky and brown, whereas that of granite is sandy, and yellowish brown, when wet and white when dry.

Garnetiferuous biotite schists form the parent material of the greater part of Chaubattia Orchard. At some places both biotite and granite appear to be present intimately mixed with each other. Biotite-muscovite-quartz schist, however, appears to be present at a few places in the orchard. Thus generally the soils might be taken to have been formed from igneous rocks.

II. METHODS AND PROCEDURE

A thorough survey of the Government Orchard at Chaubattia at points 100 ft. apart, both along and across the slopes, has been carried out. The present contribution deals with only unterraced soils and the results of the studies made in terraced soils will form the subject matter of a subsequent contribution. Pits were dug at the corresponding points of horizontal and vertical cross-lattices of the orchard map at regular distances of 100 ft. These pits were sufficiently broad for an observer to go inside and note horizon characteristics and each of the pits was dug up to the decomposing parent rock or up to impervious clay pan in typically clay profiles. In some cases, the clay pans were cut through ; underlying the clay pan, it is usual to find the parent rock at different stages of decomposition. In one case, forming a pocket between two ridges, it was found that the clay pan had a depth of about 6 ft.

Observations in regard to the characteristics of each horizon, particularly colour, texture, structure, depth and hardness, were made *in situ*, and representative samples were obtained from each horizon for laboratory study. Owing mainly to their positions along the slopes, the soils under field conditions were found to have different moisture contents and, therefore, it was felt desirable to supplement these field observations with similar observations made in the laboratory under uniform and controlled conditions. The soil samples were, therefore, air-dried and studied under air-dried and moisture-saturated conditions. This undoubtedly afforded a fuller knowledge of the horizons than that based on observations in the field alone. So far we have examined 1224 horizon soils arising out of a total of 405 profiles. The complete mechanical, chemical, and physico-chemical analyses of such a large number of soils being out of the question, attempt was made to classify the soils according to their visual and textural characteristics. Accordingly all the above-mentioned 1224 soils were classified into groups

* Geological Survey of India—private communication.

depending on the following principal soil characteristics and their combinations :—

(1) Presence of micaceous sand
(2) Presence of quartzose sand
(3) Clay content and texture
(4) Colour

Each sample was analysed for :—

(*a*) Mechanical : coarse sand, fine sand, silt and clay.
(*b*) Chemical ; SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, moisture, loss on ignition, nitrogen, organic carbon, and
(*c*) Physico-chemical : *p*H and exchange acidity.

A large number of these samples were analysed for total P_2O_5 which was invariably found to be very low. In no case the amount of P_2O_5 present exceeded 0·05 per cent. Hence, the P_2O_5 content of these soils has not been included in the calculation of R_2O_3 figures. In some cases the clay fraction has been analysed for SiO_2, Al_2O_3 and Fe_2O_3.

Analytical methods

Two-millimetre samples were used for both mechanical and chemical analyses. Hydrochloric acid extract was prepared according to the directions of the British Agricultural Education Association [Wright, 1934]. Lime and magnesia were estimated volumetrically and the former was precipitated in acetic acid medium. For the estimation of nitrogen, Kjeldahl's method was followed after pre-treating the soils with water as suggested by Bal [1925]. The quinhydrone electrode method was adopted for the determination of *p*H values. Exchangeable acidity was determined by Kappens [1927] method. Organic carbon was estimated by Walkley and Black [1934] method with chromic acid. Clay fraction was dispersed by International method, and syphoned off to 8·6 cm. depth after 24 hours. Coagulation was effected by calcium chloride. The samples were analysed by usual fusion method for the determination of silica.

The analytical data only in regard to complete profiles are detailed in Tables III-XII.

III. Data and discussion

From the data obtained it is obvious that a large number of soils of the orchard according to expectation shows primary characteristics and forms fous distinct genetic types, viz. (1) Red loams, (2) Brown forest soils, (3) Podsol- and (4) Wiesenboden or meadow soils. Although, as has already been mentioned, all of these soils arise out of two parent rocks, yet their development into clear-cut genetic types is presumably due to differences in topographical conditions and weathering processes—chemical, physical and biochemical. Of course, instances of variations within each of the soil types are somewhat numerous. The atmospheric climate of the locality is within limits uniform, but it is clear that the soil climate will be different according to the topographical conditions, i.e. the slope gradient, situation and vegetation. It is, therefore, considered desirable to present the data separately for each of the genetic types enumerated above.

RED LOAMS

Three profiles under this group have been examined in detail and the visual characteristics have been studied for 20 more profiles. The visual characteristics of the horizons constituting each of these three typical profiles are briefly given below :—

Visual characteristics of red loam profiles

Profile No.	Depth of horizon	Horizon	Description
8 R 5 .	0—1 ft.	A	Grey ; micaceous ; organic ; loamy soil. Reddish when wet.
	1 ft.—3 ft. .	B	Sandy ; greyish yellow ; micaceous soil. More yellow when wet.
	3 ft.—4 ft. .	C	Sandy ; ash grey ; very light ; structureless soil. No change when wet.
14 R 5 .	0—6 in. . .	A	Brownish grey ; slightly organic ; loamy soil with plenty of undecomposed organic matter. Darkens slightly in colour when wet.
	6 in.—1 ft. 8 in.	B	Loamy ; reddish brown soil containing little humus. Deep red brown when wet.
	1 ft. 8 in.—3 ft. 9 in.		Loamy sand, yellowish brown soil. More yellow when wet.
	3 ft. 9 in.—5 ft.	C	Loamy ; ash grey ; slightly micaceous soil of hydrogenic nature. More green when wet.
X 13 Y 33 .	0—6 in. . .	A	Granular ; grey ; loamy ; when wet reddish grey ; contains stones and undecomposed organic matter.
	6 in.—10 in. .	B	Yellowish ; micaceous ; loamy ; when wet reddish yellow. Contains stones (mica).
	10 in.—2 ft. .	C	Micaceous sandy loam ; yellowish ; more yellow when wet.

The analytical data for each of these profiles are given in Tables III and IV.

TABLE III

Analytical results of red loams (chemical determinations)

Name of profile	Depth	Moisture (per cent)	Loss on ignition (per cent)	Organic carbon (per cent)	Organic nitrogen (per cent)	C/N	pH	Insoluble matter (in strong HCl) (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	R_2O_3 (per cent)	Mgo (per cent)	CaO (per cent)
13 R 5	0—1 ft. . .	2·19	9·09	3·94	0·274	14·4	7·0	76·8	4·00	5·17	10·17	0·62	0·36
	1 ft.—3 ft. .	0·71	2·60	0·51	0·062	8·22	6·7	86·18	3·44	5·57	9·01	0·40	0·091
	3 ft.—4 ft. .	0·56	2·00	0·23	0·055	4·2	7·1	90·9	1·92	3·52	5·44	0·18	0·014
14 R 5	0—6 in. . .	2·13	8·66	3·35	0·183	18·3	6·4	76·3	4·64	6·91	11·55	0·60	0·21
	6 in.—1 ft. 8 in.	2·01	6·57	1·77	0·118	15·0	5·7	77·9	4·72	7·79	12·51	0·50	0·049
	1 ft. 8 in.—3 ft. 9 in.	0·91	2·71	0·241	0·053	4·53	5·5	85·4	3·84	6·01	9·85	0·44	0·00
	3 ft. 9 in.—5 ft. 9 in.	1·53	2·75	0·220	0·048	4·90	5·3	89·9	2·40	2·70	5·10	0·16	0·035
X13 Y 33	0—6 in. . .	2·26	7·90	3·12	0·22	14·2	6·8	76·08	4·23	8·11	12·34	0·190	0·210
	6 in.—10 in. .	1·44	4·25	1·13	0·10	11·3	6·2	81·17	3·73	7·70	11·43	0·69	0·070
	10 in.—2 ft. .	1·30	3·57	0·47	0·07	6·7	5·8	81·52	3·55	8·52	12·07	0·08	0·007

TABLE IV

Analytical results of red loams (mechanical determinations)

(Analysis of 2 mm. sample)

Name of profile	Depth	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent)	Exchange H m. e. (per cent)
13 R 5	0—1 ft. . .	19·40	41·43	18·63	15·50	0·088
	1 ft.—3 ft. .	19·63	68·09	7·37	6·68	0·35
	3 ft.—4 ft. .	21·5	62·8	9·9	6·5	0·88
14 R 5	0—6 in. . .	17·03	31·55	27·45	20·68	0·18
	6 in.—1 ft. 8 in.	15·78	31·57	28·80	23·48	3·76
	1 ft. 8 in.—3 ft. 9 in.	40·89	38·42	11·40	9·65	4·28
	3 ft. 9 in.—5 ft.	28·7	34·6	19·6	17·6	8·13
X 13 Y 33	0—6 in. . .	13·42	31·29	31·65	15·65	..
	6 in.—10 in. .	28·26	35·41	18·30	13·60	0·088
	10 in.—2 ft. .	29·95	40·27	13·65	12·75	1·40

From the results it is evident that these red loams represent the intermediate stage between lateritic and podsolic developments. Although the analytical figures show eluviation of silica relative to sesquioxides which indicates a lateritic tendency, yet considerable accumulation of organic matter in the A-horizons coupled with the acidity of the soil and humid, temperate climate tends to make the soil podsolic. On a joint consideration, therefore, of the sesquioxides in the different horizons and the comparatively low organic matter content in the sub-soils, it becomes apparent that these soil types belong to recognised red loams—intermediate between podsolic and lateritic formations. The bases, particularly silica, are relatively poor in the surface soils and seem to have been leached down to the lower horizons as against sesquioxides that decrease downwards. The position with regard to lime and magnesia is slightly different. The grass vegetation brings up some of the leached bases from lower horizons, and whatever escapes this natural enriching process, is washed away from the profile as a whole. The high C/N ratio in the A-horizons is partly due to undecomposed organic matter.

These profiles which lie mostly along slopes of hills or along ridges are generally sandy in nature. The soils, owing to the open sub-soil texture, allow free drainage and it is usual to find them dry in a few hours after a heavy rainfall. The oxidation of organic matter under these conditions is very pronounced. On analysis the surface soils are found to contain a fairly high

percentage of organic matter ; but the fact that, on moistening, the soils assum a somewhat reddish grey colour instead of dark grey shows that the humus has undergone considerable mineralization. As regards Fe_2O it may be concluded that in the sub-soils local conditions favour a higher degree of hydration than that in the surface horizon—the colour of the sub-soil being brownish yellow whereas that of the top-soils is reddish grey.

The soils of this nature are, however, not very common under the conditions of the locality, and they occur at places which receive maximum solar radiation and are always dry owing to their situation on the ridges of slopes.

In the International classification of soils the position of red loam is not clearly defined. Harrassowitz [1930] pointed out that red and yellow loams are related soil types. Marbut [1928] has observed that yellow colour is found only in sandy profiles, whereas profiles having heavy texture are red or reddish. The data from the U. S. Bureau of Soils on red and yellow soils [Joffe, 1936] definitely show podsolic tendencies. The soils studied by us more or less resemble these red and yellow Soils encountered in the United States of America. At the present stage of knowledge it is not, however, desirable to separate red and yellow loams into different groups [Robinson, 1932]. The yellow soils studied by us have, therefore, been classified as red loams.

The trend of the changes in the insoluble residue of HCl-extract and sesquioxides with depth indicates that these soils have certain red loam characteristics, whereas the nature of the variations in the *p*H value and exchangeable acidity tends to favour the classification of these as brown earths. It is thus apparent that soils similar to these form border-line cases between red loams and brown earths.

Brown forest soils

Seventeen profiles under this group have been analysed in detail and visual characters studied for 200 more profiles. The visual characteristics of the horizons constituting each of five typical profiles are given below :—

Visual characters of grey brown forest soils

Profile No.	Horizon	Depth	Description
X5 Y20	A	0—8 in. . .	Granular ; brownish grey ; clayey ; organic soil containing undecomposed organic matter. Darkens when wet.
	B	8 in.—1 ft. 7 in.	Brownish ; loam with mica bits. More brown when wet.
	C	1 ft. 7 in.—3 ft. 1 in.	Sandy loam ; brownish ; micaceous ; stony soil. More brown when wet.
X7 Y22 (Plate XLV, fig. 1)	A	0—1 ft. . .	Deep grey ; highly organic ; finely granular clayey soil containing plenty of roots. Darkens when wet.

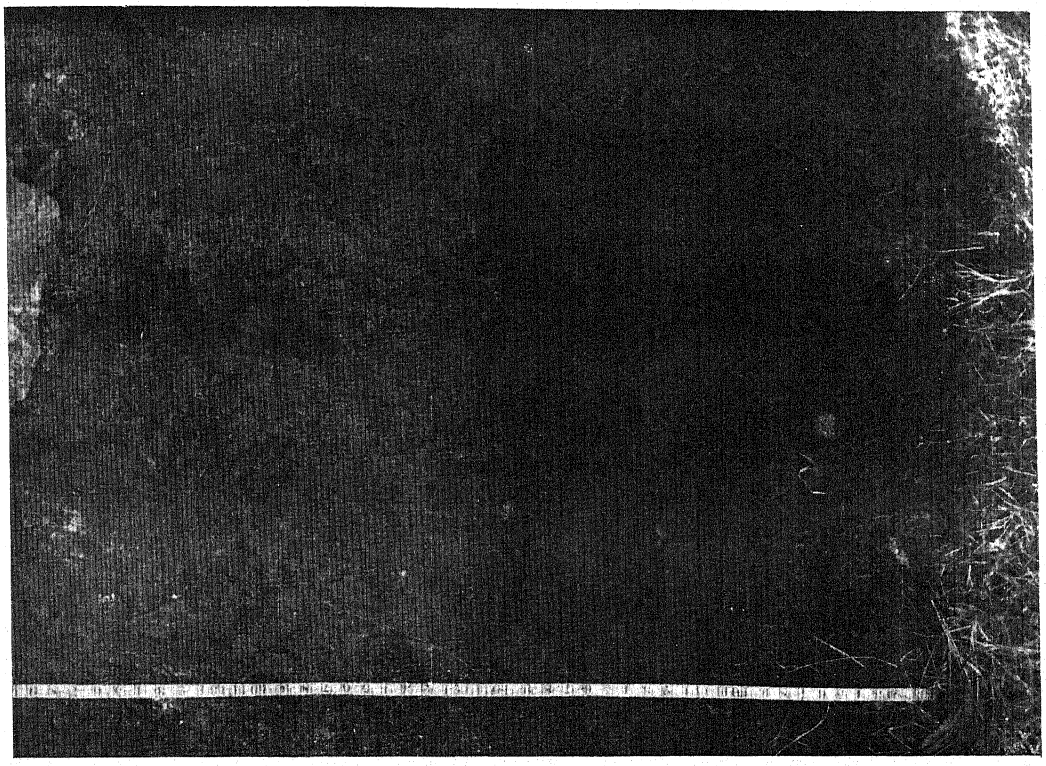


FIG. 1. Brown forest soil (X 7 Y 22)

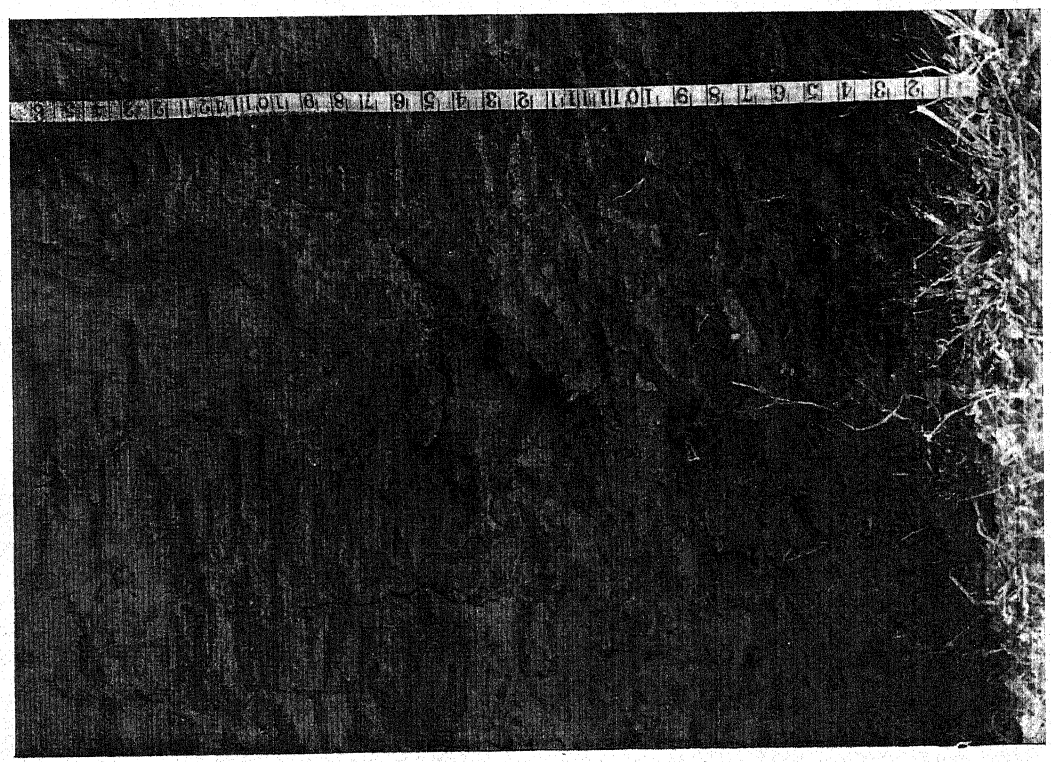
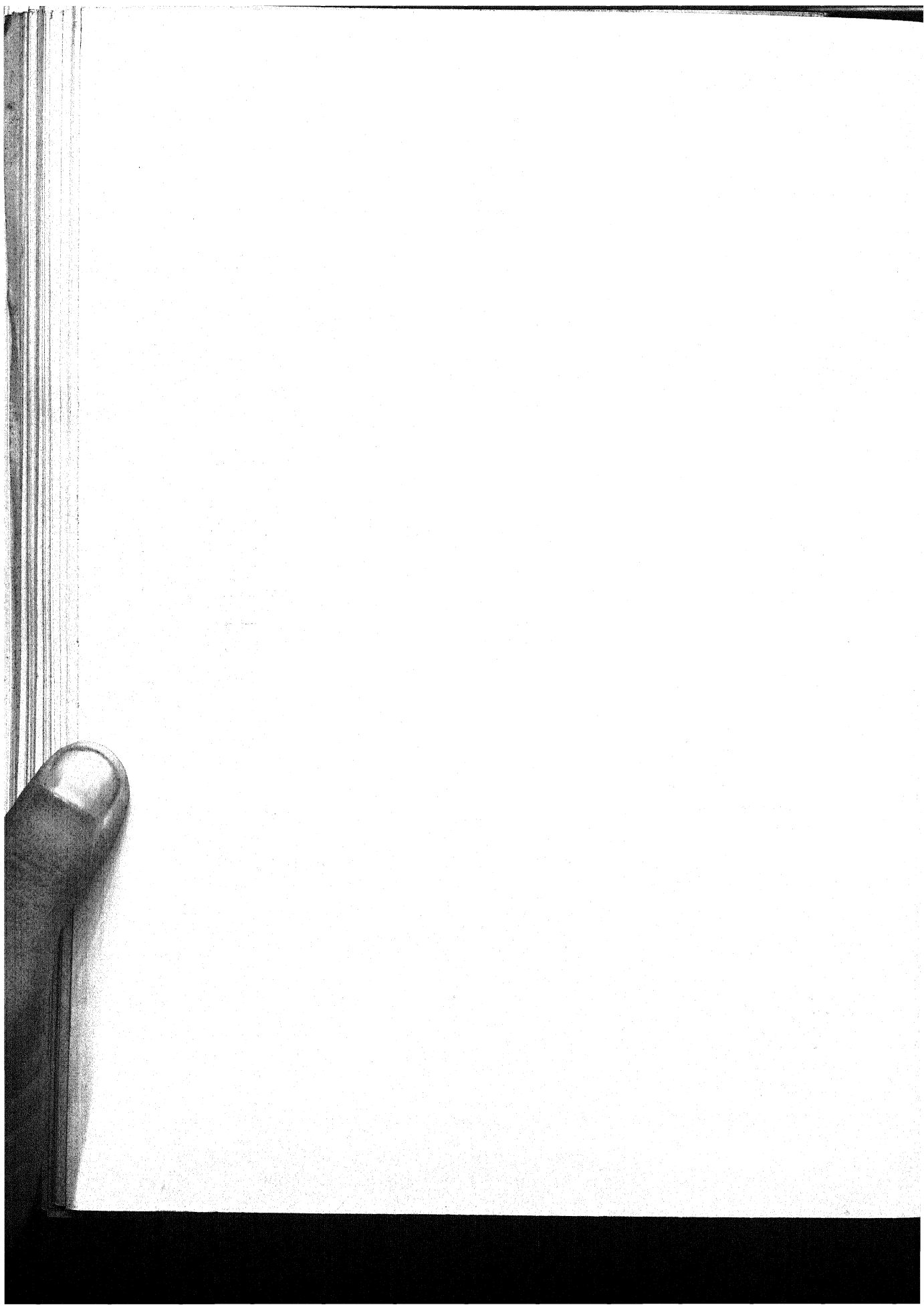


FIG. 2. Podsol profile (mixed No. IV)



Visual characters of grey brown forest soils—contd.

Profile No.	Horizon	Depth	Description
X7 Y22 (Plate XLV, fig. 1)	B	1 ft.—2 ft. 6 in.	Brownish; clayey; micaceous; slightly organic soils with roots. Dark brown when wet.
	C	2 ft. 6 in.—3 ft. 10 in.	Loam; yellowish soil containing mica bits. Brownish when wet.
X16 Y8	A	0—8 in. . .	Brownish grey; granular; slightly organic; clayey soil. Dark brownish grey when wet.
	B	8 in.—2 ft. .	Brownish clayey soil. More brown when wet.
	C	2 ft.—4 ft. .	Sandy loam; brownish; micaceous; stony soil. More brown when wet.
X14 Y23	A	0—5 in. . .	Organic; granular; micaceous; dark grey, containing mica. Darker when wet. Contains undecomposed organic matter.
	B	5 in.—8 in. .	Brownish yellow—mostly rock material—loamy soil. More brown when wet.
	C	8 in.—2 ft. 6 in.	Yellow decomposing rock material mostly mica. Deep yellow when wet.
X25 Y19	A	0—1 ft. . .	Granular, dark grey, darker when wet. Contains roots and charcoal.
	B	1 ft.—1 ft. 8 in.	Yellowish, granular, clay, contains sand. A little grey when wet.
	B_2+C	1 ft. 8 in.—3 ft. 11 in.	Hard clay, whitish grey, contains bluish hard mass at places, whitish incrustations, reddens a little when wet.

The analytical figures for the above profiles are given in Tables V and VI.

TABLE V

Analytical results of brown forest soils (chemical determinations)

Name of profile	Depth	Horizon	Moisture (per cent)	Loss on ignition (per cent)	Organic carbon (per cent)	Organic nitrogen (per cent)	C/N	*p*H	Insoluble matter (in strong HCl) (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	R_2O_3 (per cent)	MgO (per cent)	CaO (per cent)
X5 Y20	0—8 in. .	A	2·71	3·33	2·73	0·15	18·20	6·2	77·50	3·65	11·42	15·07	0·71	0·238
	8 in.—1 ft. 7 in.	B	2·04	3·56	0·51	0·06	8·47	5·8	77·82	4·21	10·38	14·59	1·16	0·119
	1 ft. 7 in.—3 ft. 1 in.	C	1·07	2·43	0·25	0·03	8·48	6·4	86·11	3·19	6·01	9·20	0·51	0·088
X7 Y22	0—1 ft. .	A	3·48	9·51	3·43	0·27	12·70	6·3	74·68	3·99	7·42	11·41	0·43	0·294
	1 ft.—2 ft. 6 in.	B	2·72	5·05	1·25	0·11	11·36	6·1	76·99	4·74	8·61	13·35	0·25	0·253
	2 ft. 6 in.—3 ft.	C	1·32	2·13	0·26	0·04	6·50	6·2	83·49	4·60	6·31	10·99	0·52	0·105
16 R 8	0—8 in. .	A	3·01	7·53	2·50	0·134	18·9	6·5	73·59	5·68	9·14	14·32	0·30	0·140
	8 in.—2 ft. .	B	2·80	4·02	0·39	0·055	7·1	5·7	76·46	6·72	8·48	15·20	0·71	0·077
	2 ft.—4 ft. .	C	1·60	3·11	0·09	0·015	6·2	5·6	81·38	5·36	7·50	12·86	0·59	0·021
X14 Y23	0—5 in. . .	A	3·41	12·24	5·46	0·34	16·1	6·8	71·53	3·65	8·21	11·86	0·64	0·280
	5 in.—8 in. .	B	2·16	5·77	1·83	0·14	13·1	6·4	77·06	4·59	9·69	14·28	0·51	0·112
	8 in.—2 ft. 6 in.	C	1·40	2·78	0·27	0·04	6·8	6·9	82·89	5·67	6·63	12·30	0·10	0·035
X25 Y19	0—1 ft. . .	A	3·77	11·44	4·76	0·25	19·04	6·2	69·15	5·23	8·84	14·07	0·69	0·322
	1 ft.—1 ft. 8 in.	B_1	2·82	4·03	0·72	0·08	9·00	5·8	76·87	5·57	9·09	14·6	1·00	0·049
	1 ft. 8 in.—3 ft. 11 in.	B_2 & C	2·68	3·12	0·25	0·05	5·00	6·4	78·07	5·47	8·50	13·97	1·23	0·070

TABLE VI

Analytical results of brown forest soils (mechanical determinations)

(Analysis of 2 mm. sample)

Name of profile	Depth	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent	Exchange H m. e. (per cent)
X5 Y20	0—8 in. . .	4·53	35·82	31·25	21·75	0·18
	8 in.—1 ft. 7 in.	2·88	43·43	31·03	19·70	0·26
	1 ft. 7 in.—3 ft. 1 in.	15·98	52·30	18·30	11·85	0·35
X7 Y22	0—1 ft. . .	4·61	37·14	25·15	20·75	0·35
	1 ft.—2 ft. 6 in.	7·34	36·25	28·00	23·85	3·33
	2 ft. 6 in.—3 ft.	11·36	51·39	21·85	14·15	2·71
16 R 8	0—8 in. . .	4·89	26·48	37·10	27·65	7·25
	8 in.—2 ft. .	4·24	27·57	38·30	29·50	6·56
	2 ft.—4 ft. .	33·84	43·70	7·90	16·50	3·24
X14 Y 23	0—5 in. . .	15·52	30·11	26·25	16·40	..
	5 in.—8 in. .	24·83	36·55	15·85	16·40	0·044
	8 in.—2 ft. 6 in.	30·72	43·21	13·70	11·0	..
X25 Y19	0—1 ft. . .	1·05	22·48	39·10	23·10	..
	1 ft.—1 ft. 8 in.	0·82	28·60	42·30	23·35	..
	1 ft. 8 in.—3 ft. 11 in.	1·00	31·63	36·95	27·05	..

These soils possess characteristics which are essentially similar to those identified as ' Braunerde ' of Ramann. Although varying only in texture, the majority of the soils so far studied at Chaubattia possess the characteristics of this group.

The zone of accumulation of organic debris or jungle litter, i.e. A_0-horizon is usually absent, which is due to absence of forest cover and intense surface erosion. The first surface layer of soil is, therefore, rich in humified matter and reaches a depth of about a foot. It is usual to find most of the plant roots crowding in this horizon, the structure of the soil aggregates is usually granular. This horizon is always extremely acid. The highest quantity of lime in loamy

or sandy loam profiles is associated with the surface organic layer. The contents of magnesia in this horizon are usually lower than that in the next horizon.

The pre-eminent character of the second horizon is its distinctly brownish colour. In most roadside cuttings one cannot mistake this layer extending in a tongue-like fashion into the third horizon. In loamy soil, therefore, this is the first zone of accumulation of sesquioxides, particularly iron, which is apparently the reason of the striking colour of this horizon. The soils of this horizon are more acid than those of the preceding horizon and have lower content of organic matter and lime. This horizon in most cases shows the highest amount of magnesia. The aggregates are some times granular, but more often are structureless. The position of profiles along the slopes determines the textural character of this horizon. In mild slopes it has a lighter texture than the one preceding it (viz. X5Y20); but at the bottom of slopes or pockets of hills this horizon shows a granular structure and heavier texture; but the brown colour of the horizon under all conditions is very apparent.

The third horizon shows different characteristics depending on the position of the profile along the slopes. On steep slopes of about 45° or more this horizon is usually yellow and sandy, turning slightly brown when wet. It is usual to find feeder roots invariably avoiding this horizon. The soil in this case is structureless and sandy.

In sesquioxides and lime this horizon is the poorest. On account of the richness of the parent rock in magnesia, the latter in the case of some profiles is found in higher quantity in this horizon, e.g. X7 Y22. In the case of those profiles which are situated along slopes of less than 45° this horizon shows a heavier texture, and is more brownish yellow in colour with sometimes dark bluish incrustations, e.g. X25 Y19. In the pockets of hills or at the bottom of slopes, owing probably to impeded subsoil drainage, this horizon shows rock-like consistency. The structural aggregates in the latter case are angular. The soil material synthetically is a mixture of infiltered clay and decomposing parent material. In relative chemical attributes this horizon is not very different from the usual C-horizons of the loamy grey brown profiles.

The pan formation in the case of brown soils takes place in the pockets of hills which are the only places where drainage takes place vertically. At other places it is usual to expect the subsoil-drainage flow parallel to the surface of the bed rock or surface soil. Along steep slopes translocation of material takes place parallel to the surface and this might be the reason why on steep slopes we do not meet with pan formation while this is invariably present at the bottom of slopes, or along slopes having about 20° inclination.

The above characteristics of the brown forest soils studied by us are not strictly analogous to those of the types described by Ramann [1928] to which the universal name 'Braunerde of Ramann' is given. The latter have normally a neutral or slightly alkaline reaction, and hence the humus bodies are not found under dispersed condition. Glinka [1928] considered these soils as a variety in the podsol zone formed on parent material rich in lime.

Tamm [1930] however has recognised two sub-types of brown soils in Southern Sweden and has divided them into climatic and acclimatic types. The former type of formation develops on parent material poor in lime, whereas the latter forms on calcareous material. Mitchell and Muir [1935] have adduced evidence showing that brown soils of England do not show the

characteristics usually associated with brown soils of Ramann. That the brown forest soils have been developed under podsolic conditions have been recognised by all the authors cited. Besides Ramann has recognised that ' In no other formations does the parent rock exercise such a great influence as in brown earths' . The brown soils studied by us therefore can be considered as a sub-type of brown forest soils formed from acid igneous rock having analogous development in Miami and Russell series. Baldwin [1928], has analysed some of these brown soils which appear to have the same general characteristics as our soils.

For elucidating more fully the pedogenic processes undergoing in these soils, it was considered desirable to analyse the clay fraction alone for SiO_2, Al_2O_3 and Fe_2O_3. The results for two typical profiles are given in Table VII.

TABLE VII

Analysis of clay fraction—brown forest soils

Profile	Depths	Horizon	SiO_2 (per cent)	Fe_2O_3 (per cent)	Al_2O_3 (per cent)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
X5 Y20	0—8 in.	A	41·91	15·41	22·09	3·22	2·22
	8 in.—1 ft. 7 in.	B	44·12	15·41	18·94	3·95	2·60
	1 ft. 7 in.—3 ft. 1 in.	C	44·27	15·17	17·03	4·41	2·81
X7 Y22	0—1 ft.	A	44·40	11·58	25·02	3·01	2·34
	1 ft.—2 ft. 6 in.	B	42·28	12·78	26·82	2·67	2·11
	2 ft. 6 in.—3 ft. 10 in.	C	43·06	11·98	25·72	2·84	2·29

The data given in Table VII clearly indicate that there is no marked eluviation of sesquioxides or silica in these profiles—a characteristic which is typical of continental brown forest soils. Further the silica-alumina ratio as well as the silica-sesquioxide ratio show that within limits the consistency of the clay complex is the same throughout the profile.

PODSOLS

Twelve profiles showing the characteristics of podsolic development have been analysed in detail and visual characters have been studied for 50 more

profiles. The visual characters of the horizons constituting each of six typical profiles are given below :

Visual characters of podsolic profiles

Profile Nos.	Horizon	Depths	Characters
X8 Y25	A_1	0—7 in. . .	Dark grey ; clayey ; finely granular ; organic soil containing roots ; darkens in colour when wet.
	A_2	7 in.—2 ft. .	Yellowish brown ; sandy loam ; stony soil. More brown when wet.
	B+C	2 ft.—3 ft. 2 in.	Brownish clayey ; slightly granular soil. More brown when wet. The clay particles have dark bean-shaped iron concretions.
X7 Y20	A_1	0—1 ft. 3 in. .	Dark grey ; coarsely granular ; clayey soil. More dark when wet.
	A_2	1 ft. 3 in.—2 ft. 4 in.	Sandy ; micaceous ; stoney ; yellowish horizon containing some undecomposed rock. More brown when wet.
	B+C	2 ft. 4 in.—3 ft. 10 in.	Brownish ; clayey ; micaceous ; stony soil. More brown when wet.
9 S I	A	0—1 ft. .	Greyish brown clayey. More brown when wet. Granular.
	A_1	1 ft.—2 ft. 8 in.	Clayey ; brownish soil. More brown when wet.
	A_2	2 ft. 8 in.—3 ft. 6 in.	Reddish brown. Sandy micaceous soil. Deep brown colour when wet.
	B + C	3 ft. 6 in.—4 ft. 6 in.	Clayey ; greyish brown soil. More brown when wet.
8 R 5	A	0—1 ft. 2 in.	Dark grey ; granular ; loam with some undecomposed organic matter. More dark when wet.
	A_1	1 ft. 2 in.—2 ft. 6 in.	Brownish grey ; heavy loam. Slightly dark when wet.
	A_2	2 ft. 6 in.—3 ft. 4 in.	Brownish yellow ; loam ; lighter than above. More yellow when wet.
	B	3 ft. 4 in.—5 ft.	Hard, lumpy, brown pan with white cementation and dark incrustations. More brown when wet.

Visual characters of podsolic profiles—contd.

Profile Nos.	Horizon	Depths	Characters
Mixed No. 4 (Plate XLV, fig. 2)	A	0—2 in. . .	Granular, with brown markings, loamy; dark grey when wet.
	A_2	2 in.—8 in. .	Soil same as above mixed with some stones and single-grain sand.
	B_1	8 in.—1 ft. 5 in.	Whitish brown with sandy cementation; dark and brown incrustations loam. More brown when wet.
	B_2	1 ft. 5 in. and below	Dark grey, angular, clayey hard soil with black incrustations. More dark in colour when wet.
9R 4	A_1	0—1 ft. . .	Greyish brown; granular; organic loam. More dark when wet.
	A_2	1 ft.—4 ft. 10 in.	Granular; greyish brown; slightly micaceous; loam. Slightly darker when wet.
	B_1	4 ft. 10 in.—6 ft. 10 in.	Dark grey; heavy loam; more dark when wet.
	B_2	6 ft. 10 in.—7 ft. 10 in.	Brownish grey; heavy loam; more dark when wet.
	B_3+C	7 ft. 10 in. and below	Reddish brown; hard clay pan, with whitish cementations and dark incrustations. More red when wet.

The complete chemical analysis and mechanical compositions of the above profiles are given in Tables VIII and IX.

This type of development is met with under mild slope gradients, and in the pockets of hills and ridges, and in the shady places of the orchard. The surface erosion due to the particular topography is not as intense as in grey brown forest soils. Although there is considerable accumulation of organic matter from the decomposing leaves and grasses, the surface soil does not tend to be peaty. The horizon differentiation is very clear in all cases.

The first horizon contains a soil rich in humus in a dispersed condition which gives the soil a granular structure. As expected, the maximum crowding of the plant roots is found in this horizon. The colour of the soil shades from dark grey to brownish grey. The soil is mostly clayey which is not much indurated owing to the presence of humus. Depending upon the position of the profile along slopes this horizon sometimes shows a sub-horizon (e.g. 9SI, and 8R5) and the total depth of 3 ft. is recorded for such horizons. Sub-horizons indicated above show the characteristics of the B-horizon of the brown forest soils, namely alluvial additions of colloidal matter and sesquioxides from the preceding horizons.

TABLE VIII

Chemical analysis of podsolic profiles

Name of profile	Depth	Moisture	Loss on ignition	Organic carbon	Organic nitrogen	C/N	pH	Insoluble matter (in strong HCl)	Fe_2O_3	Al_2O_3	R_2O_3	MgO	CaO
		Per cent	Per cent	Per cent	Per cent		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
X8 Y25 A_1	0—7 in.	3·41	9·86	3·82	0·23	16·60	6·8	72·02	4·56	8·42	12·98	0·40	0·413
X8 Y25 A_2	7 in.—2 ft.	1·43	2·54	0·34	0·05	6·80	6·3	82·88	3·82	7·70	11·52	0·12	0·126
X8 Y25 B+C	2 ft.—3 ft. 2 in.	2·19	4·16	0·30	0·06	5·00	5·6	75·86	5·62	9·66	15·28	0·31	0·105
X7 Y20 A_1	0—1 ft. 3 in.	2·99	8·96	3·59	0·25	14·36	7·0	73·20	3·47	9·67	13·14	0·53	0·462
X7 Y20 A_2	1 ft. 3 in.—2 ft. 4 in.	1·23	2·70	0·36	0·08	4·45	6·8	85·10	3·19	6·39	9·58	0·34	0·147
X7 Y20 B+C	2 ft. 4 in.—3 ft. 10 in.	1·64	2·49	0·08	0·03	2·60	5·6	81·46	4·11	8·25	12·36	0·50	0·070
SI A	0—1 ft.	2·92	5·75	1·37	0·126	10·96	6·3	76·10	6·40	6·85	13·25	1·014	0·161
SI A_1	1 ft.—2 ft. 8 in.	3·50	4·05	0·32	0·050	6·35	5·6	76·31	6·80	7·31	14·11	0·988	0·084
SI A_2	2 ft. 8 in.—3 ft. 6 in.	1·52	2·68	0·070	0·018	3·86	5·5	86·04	3·76	5·10	8·86	0·336	0·021
SI B+C	3 ft. 6 in.—4 ft. 6 in.	2·78	3·55	0·213	0·036	5·73	6·0	79·73	6·16	5·28	11·44	0·823	0·049
8R5 A	0—1 ft. .. in.	3·60	8·48	2·88	0·171	16·9	6·0	72·68	5·28	7·93	13·21	0·65	0·140
8R5 A_1	1 ft. 2 in.—2 ft. 6 in.	3·42	5·41	1·21	0·098	12·4	5·7	73·51	6·08	9·91	15·99	0·73	0·121
8R5 A_2	2 ft. 6 in.—3 ft. 4 in.	2·56	4·19	0·37	0·050	7·2	5·6	77·2	5·44	8·57	14·01	0·239	0·035
8R5 B+C	3 ft. 4 in.—5 ft. 6 in.	3·30	4·25	0·30	0·060	5·0	5·5	76·17	6·40	9·15	15·55	0·91	0·177
Mixed No. 4 A	0—2 in.	3·86	13·89	6·08	0·440	13·81	5·9	68·08	4·63	8·76	13·39	0·57	0·161
Mixed No. 4 A_1	2 in.—8 in.	2·86	7·96	2·730	0·252	10·81	5·7	75·56	4·23	8·53	12·76	0·66	0·077
Mixed No. 4 B_1	8 in.—1 ft. 5 in.	3·04	3·53	0·470	0·066	7·12	5·9	78·15	5·83	7·88	13·71	1·01	0·172
Mixed No. 4 B_2	1 ft. 5 in. and below	3·86	4·43	0·86	0·077	11·20	6·2	75·00	6·21	8·75	14·96	0·86	0·462
9R4 A_1	0—1 ft.	3·87	10·82	3·59	0·181	19·8	6·0	71·0	5·36	8·51	13·87	0·236	0·196
9R4 A_2	1 ft.—4 ft. 10 in.	3·55	5·12	0·94	0·073	12·9	5·7	75·4	5·84	8·34	14·18	0·449	0·077
9R4 B_1	4 ft. 10 in.—6 ft. 10 in.	4·19	7·17	1·79	0·083	21·6	5·6	72·7	5·60	9·77	15·37	0·328	0·056
9R4 B_2	6 ft. 10 in.—7 ft. 10 in.	3·39	4·16	0·54	0·055	9·8	5·5	76·7	5·76	8·35	14·11	0·300	0·049
9R4 B_3+C	7 ft. 10 in. and below	4·86	4·06	0·12	0·035	3·4	5·8	73·3	6·64	9·70	16·34	0·233	0·084

TABLE IX

Mechanical analysis of podsolic profiles

(Analysis of 2 mm. sample)

Name of profile	Depth	Coarse sand	Fine sand	Silt	Clay	Exchange H+ m.e.
		Per cent	Per cent	Per cent	Per cent	Per cent
X8 Y25	0—7 in.	6·42	32·13	33·05	24·20	0·088
	7 in.—2 ft.	12·42	40·13	25·20	18·60	1·75
	2 ft.—3 ft. 2 in.	8·46	32·70	25·00	30·90	2·27
X7 Y20	0—1 ft. 3 in.	6·14	31·80	30·45	23·20	..
	1 ft. 3 in.—2 ft. 4 in.	13·55	47·93	21·05	15·50	..
	2 ft. 4 in.—3 ft. 10 in.	..	39·48	26·50	22·45	0·18
9SI	0—1 ft.	4·12	23·68	40·22	25·88	0·088
	1 ft.—2 ft. 8 in.	1·83	23·50	39·13	31·55	3·98
	2 ft. 8 in.—3 ft. 6in.	19·28	49·51	14·30	18·40	2·98
	3 ft. 6 in.—4 ft. 6 in.	8·18	29·31	32·82	28·98	0·33
8R5	0—1 ft. 2 in.	3·38	24·66	39·80	29·35	2·62
	1 ft. 2 in.—2 ft. 6 in.	3·70	21·33	40·50	34·75	2·45
	2 ft. 6 in.—3 ft. 4 in.	3·98	24·9	43·30	28·50	2·50
	3 ft. 4 in.—5 ft.	0·57	21·81	43·75	32·85	1·66
Mixed No. 4	0—2 in.	2·83	22·09	30·75	26·40	Trace
	2 in.—8 in.	5·94	29·53	33·15	22·60	0·525
	8 in.—1 ft. 5 in.	2·28	28·48	40·40	24·15	Trace
	1 ft. 5 in. and below.	0·31	20·98	40·75	30·75	Trace
9R4	0—1 ft.	3·03	21·9	40·8	27·7	0·26
	1 ft.—4 ft. 10 in.	5·34	24·7	39·2	28·6	4·2
	4 ft. 10 in.—6 ft. 10 in.	3·18	18·2	40·2	33·4	4·73
	6 ft. 10 in.—7 ft. 10 in.	5·66	21·5	42·5	27·9	3·68
	7 ft. 10 in. and below	1·79	21·1	40·6	34·2	1·75

This observation is certainly peculiar. In no podsolic development a sub-horizon of the nature enumerated here has been found associated with the A_1-horizon, as the preceding horizon is neither peaty nor possesses any decomposed organic accumulation.

Underlying the A_1-horizon is found the A_2-horizon which in the cases of loamy profiles is mostly sandy loan (e.g. X8 Y25, X7 Y20) and is the zone of maximum eluviation.

In the cases of clayey profiles this horizon shades from yellow to brown with sandy grains showing more or less a bleached appearance cemented round the structural soil mass. In all these profiles physical eluviation particularly of clay is very apparent, and among the soil ingredients the content of fine sand in this horizon is maximum. Amongst the chemical attributes, it is interesting to note that in this horizon the largest amount of SiO_2 (insoluble matter in strong HCl) is associated with the least amount of sesquioxides, and unlike grey brown forest soils, we find lowest amount of magnesia in this horizon. Excepting a few profiles (e.g. X8 Y25 and X7 Y20) we also find considerable eluviation of lime from this horizon. In organic carbon and nitrogen, for the majority of the profiles, this horizon is found to be strikingly impoverished. Thus in short the A_2-horizon is considerably eluviated of finer matter, sesquioxides and bases.

Underlying the A_2-horizon, the horizon of maximum illuviation, namely 'B' is situated. This horizon in most cases cannot be differentiated into B_1 and B_2. In loamy profiles it is, in the majority of cases, brown and clayey, and when moist some sort of a granular structure is apparent. There are imbedded in the soil mass bean-shaped, sometimes needle-like, black iron concretions.

In clayey profiles this horizon shows rock-like consistency by forming a hard clay pan. Two types of such pans are encountered under our conditions. The first one of importance possesses a brownish colour and soil aggregates are arranged in prismatic form (e.g. 4th horizon of 8R5). The second type shows a dark grey colour, with angular soil aggregates (e.g. 4th horizon of mixed No. 4). These two types of pans are essentially different from each other as will be seen from Table IX*a*.

It is interesting to note that in some profiles these two types of pans are found to occur together (e.g. 9R4) where the humus pan precedes the iron one. In all the above cases, however, a white sandy cementation is found round the soil aggregates which appear to be, as will be clear from the table on page 1012, eluvial material of the A_2-horizon mechanically carried downwards.

Chemical analysis of the clay pans (Table IX*a*) shows that illuviation of sesquioxides and bases takes place in this horizon.

The C-horizon is generally found to be constituted of decomposing rock mixed with infiltered clay and there is no clear demarcation of boundaries between the B and C horizons, which appear to be blended together. The third horizon of X7 Y20 seems to contain decomposing rock debris mixed with some finer material washed down from the preceding horizons. In clayey profiles, this composition is found towards the bottom of the B-horizon.

TABLE IX*a*

Analytical results of some clay pans

Name of profile	Depth	Description	Clay	Moisture	Loss on ignition	Organic carbon	Organic nitrogen	C/N	SiO_2	Fe_2O_3	Al_2O_3	*p*H
			Per cent	Per cent	Per cent	Per cent	Per cent		Per cent	Per cent	Per cent	
X14 Y25	4 ft. 1 in.—4 ft. 10 in.	Iron pan	25·25	2·83	3·68	0·51	0·06	8·5	78·36	3·23	10·69	5·1
X15 Y15	3 ft. 5 in. and below	Iron pan	26·15	3·02	2·56	0·34	0·06	5·21	76·95	3·86	10·13	...
8R5	3 ft. 4 in.—5 ft.	Iron pan	32·85	3·30	4·25	0·30	0·060	5·0	76·17	6·40	9·15	4·1
X15 Y28	1 ft. 6 in.—2 ft.	Humus pan	23·10	2·91	5·30	1·48	0·08	18·5	78·48	4·45	8·47	3·8
9R4	4 ft. 10 in.—6 ft. 10 in.	Humus pan	33·4	4·19	7·17	1·79	0·083	21·6	72·7	5·60	9·77	3·9

Chemical analysis of cement soil mass of B-horizon

Components	SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	CaO	MgO
Cement . .	86·53	1·84	5·21	7·05	0·37	0·91
Hard clay .	..	..	..	..	..	..
(Mean of four) .	77·06	9·22	5·27	14·49	0·20	1·05

Podsolic formations have been studied in greater detail than any other formations owing to their occurrence in Northern Europe and Russia by such eminent authorities in soil science as Ramann, Glinka, Dokuchaev, etc. The peculiar features of this development is to no small extent responsible for the development of the modern conception of soil science. Various hypotheses about the causes responsible for the development of the peculiarities of podsols have been advocated from time to time. Ramann [1928] and Dokuchaev [1879] advanced the theory that organic acids are responsible for the formation of podsols. The bleached appearance of the A_2-horizon had been attributed to the light coloured crenic acid by Tumin [1911]. Glinka [1928] was of the opinion that colloidal matters of the A-horizon are washed down under the protective action of humus. Thus the horizon so impoverished of finer matter assumes a whitish colouration owing to the presence of qurtz sand. Robinson [1932] considered that the dominant factors in the development of the podsols were the prevalence of intense bleaching owing to excessive humid condition and parent material with poor base resource. Gedroiz's [1929] essentially physico-chemical views on the formation of the A_2-horizon are the decomposition of the unsaturated aluminium silicates into silica and sesquioxides after the colloidally dispersed humic acids which have been carried downwards. The recent investigation of Mattson [1933] suggests that the processes of podsolisation are related to the condition of acid hydrolysis prevalent in the podsolic zones. A-horizon under these conditions becomes saturated with hydrogen ions and a partial decomposition of the aluminium silicate complex necessarily takes place. Owing to a periodic shift of the *p*H of the environment the sesquioxides move downwards leaving behind silica. These deposit a short distance below owing primarily to *p*H of the B-horizon which controls the electrostatic forces. Ramesov [1937] has criticised this view of acid weathering. On account of the forest condition the dispersion is attributed by him to be brought about by ammonia formed from the decomposing organic debris. The absolute composition of the concretions found in the B-horizon has been studied by Morozov [1938] and Winter [1938] who find these to be richer in sesquioxides and manganese but poor in silica.

Aaltonen [1938] has found that in young soils the organic colloids, particularly of iron, are precipitated at comparatively lower depths than in old soils. The former are more acid and poorer in base-mineral indices. From this it appears that there are two distinct phases in the podsolic formations. At first the soils deepen with age and after a certain time the process is reversed ; B-horizon rises to the surface accompanied by the gradual decrease of soil acidity. When the soils of Chaubattia are viewed from this angle, the peculiar observation as the lack of a humus pan before iron one is fully understood, and the extreme acidity may, therefore, be attributed partly to the age of the profiles.

As in the case of the brown forest soils, clay fraction of the two of profiles discussed above was also analysed for SiO_2, Al_2O_3 and Fe_2O_3. The data are given in Table X.

TABLE X

Analysis of clay fraction—podsolic profiles

Profile	Depth	Horizon	SiO_2 Per cent	Fe_2O_3 Per cent	Al_2O_3 Per cent	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
Mixed No. 4	0—2 in.	A_1	47·40	8·38	19·32	4·16	3·24	3·68
	2 in.—8 in.	A_2	47·02	8·78	19·02	4·19	3·24	3·39
	8 in.—1 ft. 5 in.	B_1	48·34	11·58	14·52	5·64	3·74	1·96
	1 ft. 5 in. and below	B_2	47·82	11·98	14·52	5·58	3·66	1·90
9S1	0—1 ft.	A	44·20	11·58	27·22	2·75	2·16	3·66
	1 ft.—2 ft. 8 in.	A	45·06	12·78	25·22	3·02	2·29	3·09
	2 ft. 8 in.—3 ft. 6 in.	A_2	45·94	15·13	18·17	4·29	2·80	1·88
	3 ft. 6 in.—4 ft. 6 in.	B+C	45·93	12·38	17·22	4·52	3·10	2·18

It appears from the figures given in Table X that although the clay-complex judged by the SiO_2/R_2O_3 ratios remains constant at all depths of the profiles, a marked eluviation in regard to Fe_2O_3 is obvious. This is also borne out by the diminution of the Al_2O_3/Fe_2O_3 ratio in the B-horizons, showing that, according to expectation, there has been a greater mobility in respect of Fe_2O_3 than Al_2O_3. The results as a whole, however, indicate that in the formation of soils in these parts, physical weathering plays a far more important role than chemical weathering. The somewhat erratic nature of the values given by the last horizon of 9S1 profile is attributed to the fact that it is a composite of B and C-horizons.

WIESENBODEN FORMATIONS

Four profiles under this group were analysed in detail and visual characters have been studied for fourteen more profiles. The visual characteristics of the horizons constituting each of three typical profiles are briefly given below :—

Visual characteristics of Wiesenboden profiles

Profile No.	Horizon	Depth	Characteristics
9R1	A	0—6 in.	Organic ; loamy ; dark grey soil. More dark when wet. Containing undecomposed organic matter.
	B+C	6 in.—1 ft.	Sandy loam ; slightly organic ; grey soil with undecomposed mica bits. Darkens when wet.
A9 R4	A	0—6 in.	Dark grey ; granular with brown spots ; sandy loam ; micaceous. More dark when wet.
	A_1	6 in.—1 ft. 2 in.	Granular ; dark grey ; sandy loam, darker than above, with a bluish tinge and dirty brown spots round mica pieces. This horizon contains mica stones.
	B+C	1 ft. 2 in.—1 ft. 6 in.	Yellowish ; micaceous ; sandy soil ; brownish yellow when wet.
26 Y19	A_1	0—9 in.	Granular ; brownish grey ; micaceous loam with few stones. More dark when wet.
	A_2	9 in.—1 ft. 3 in.	Greyish brown ; stony loam ; micaceous ; granular. Darkens when wet.
	B_1	1 ft 3 in.—2 ft.	Angular ; grey lumpy ; heavy loam. Micaceous with mica stone imbedded in soil mass and dark incrustations ; dark grey when wet.
	B_2+C	2 ft.—3 ft.	Greenish blue ; loam ; micaceous with some mica stones ; rather heavy ; reddish brown spots at places. Dark blue when wet.

The detailed analytical figures of the above profiles are given in Tables XI and XII.

TABLE XI

Results of chemical analysis of Wiesenboden formations

Name of profile	Depth	Moisture	Loss on ignition	Organic carbon	Organic nitrogen	C/N	pH	Insoluble matter	Fe_2O_3	Al_2O_3	R_2O_3	MgO	CaO
		Per cent	Per cent	Per cent	Per cent			Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
9R1 A	0—6 in.	4·98	15·29	8·23	0·515	16·0	6·4	66·63	4·80	5·17	9·97	0·47	0·658
B+C	6 in.—1 ft.	2·08	4·79	1·68	0·134	12·5	6·6	81·61	4·56	5·63	10·25	0·31	0·175
A9 R4 A	0—6 in.	2·73	8·10	3·03	0·255	11·88	6·8	78·68	3·37	6·15	9·52	0·35	0·245
A_1	6 in.—1 ft. 2 in.	2·33	5·55	2·03	0·164	12·38	6·4	77·11	3·35	5·68	9·03	0·44	0·175
B+C	1 ft. 2 in.—1 ft. 6 in.	1·55	3·41	0·66	0·070	9·43	6·3	84·01	4·75	8·00	12·75	0·52	0·084
A62 Y19 A_1	0—9 in.	3·44	8·80	3·55	0·225	15·78	6·7	74·61	4·51	7·16	11·67	0·72	0·2100
A_2	9 in.—1 ft. 3 in.	2·66	5·23	1·60	0·118	13·56	6·8	77·99	4·79	8·04	12·83	0·57	0·147
B_1	1 ft. 3 in.—2 ft.	2·79	5·25	1·56	0·111	14·06	6·6	74·68	4·95	8·65	13·60	0·43	0·238
B_2+C	2 ft.—3 ft.	2·40	5·37	2·03	0·074	27·44	6·5	81·05	4·01	7·08	11·09	0·62	0·330

TABLE XII

Mechanical analysis of Wiesenboden formations

(*Analysis of 2 mm. sample*)

Name of profile	Depth	Coarse sand	Fine sand	Slit	Clay	Exchange H m. e.
		Per cent	Per cent	Per cent	Per cent	Per cent
9RI	0—6 in.	8·27	23·09	32·25	23·25	0·088
	6 in.—1 ft.	26·57	32·17	23·80	15·80	0·088
A9 R4	0—6 in.	13·40	45·69	19·65	12·25	
	6 in.—1 ft. 2 in.	24·81	38·38	19·30	12·25	
	1 ft. 2 in.—1 ft. 6 in.	22·98	42·72	23·50	10·05	
A62 Y19	0—9 in.	14·94	36·33	23·80	14·90	
	9 in.—1 ft. 3 in.	15·68	37·02	24·50	17·95	
	1 ft. 3 in.—2 ft.	9·50	30·23	35·15	20·55	
	2 ft.—3 ft.	12·10	33·93	33·35	16·25	

This type of profile development is not by any means very common in these parts and is usually met with near *nullas* or water streams and cool and shady low-lying places of the orchard. Owing to very high ground water-level, the soil remains always moist, and during winter a thick matting of frost covers the soil surface during the entire season. The organic matter due to water-logged condition is not completely decomposed to humus, and it is usual to find a horizon of organic debris of about an inch thick on the surface soil in a semi-decomposed state. The surface horizon is, therefore, very dark in colour, and coarsely granular. It is found that *in situ* this dark colour deepens downwards. In some profiles, e.g. A9 R4 it has been found that the organic horizon occurs as two sub-horizons with distinct marks of demarcation and it is the lower horizon which appears to be more organic than the surface. In reality however the surface soil on analysis gives higher carbon content owing presumably to undecomposed organic matter. The carbon-nitrogen ratio of this layer on the other hand is found to be higher than that of the surface soil. But in most cases these profiles are marked by their shallowness and waterlogged conditions. The second horizon is often found to be a decomposing rock, sometimes brown but more often slightly bluish and invariably very light, stony and structureless. Considerable

amount of organic matter is sometimes found in this horizon, but the difference in the organic matter content between this horizon and the surface layer is very marked. From the description of the profiles as given above it is clear that this type of profile development is essentially hydrogenic in nature. As a result of intensive soil survey carried out at Chaubattia it is obvious that profiles of this nature are by no means common under the existing conditions of the locality.

The formation of soils falling under this group is in fact due to certain inter-zonal processes resulting in an aggregate profile similar to that of Wiesenboden. The chief pre-disposing causes leading to the evolution of soils of this type at Chaubattia are waterlogging of the sub-soil, low temperature, and presence of vegetations such as grasses and undergrowths like *Rhubus, Renunculus, Ophiopogon, Pteris,* etc.

Another striking point which emerges out of these observations is that, although in general this group can be classified as Wiesenboden, the profile development shows two distinct phases, namely brown forest and podsolic characteristics. Of the profiles described above A62 Y19 shows definite podsolic tendencies, whereas the characteristics of the grey brown forest soils are indicated in the rest.

These soils are better known as 'meadow soils' after Robinson [1932] who describes these as 'soils whose profile characteristics are dominated by the occurrence of a high water-table or an impervious layer impeding percolation'. Kellog [1936] thinks that, when properly drained by artificial means, Wiesenboden provides some of the most fertile land in the world for crops. Its occurrence in other soil groups has also been indicated by him.

The question of gley formation in the podsol zone has been discussed by Frosterus [1914] and the role that the dissolved oxygen plays in soil water in gley formations has been investigated in detail by Tamm [1925]. This has thrown considerable light on the peculiar features of hydrogenic soils.

General discussion

The detailed study of soils developed under the climatic conditions of Chaubattia in Kumaun clearly shows that local conditions as a whole favour the development of soils similar to, but not identical with, the brown soils of the international groups. The processes giving rise to this type of development seem to be similar to those causing the development of podsols. The surface shows a well-developed organic horizon which does not tend to be peaty and the structural aggregates are finely granular. The second horizon possesses a brownish to reddish brown colour. This may be attributed to the dehydration and oxidation of sesquioxide sols eluviated under the protective action of acid humus from the upper horizon, since according to Mattson [1933] high acidity cannot favour the mobilization of silica although the sesquioxide soils may be gradually washed down under such conditions. The presence of humus in excess sometimes masks this brown colour and causes the development of a greyish brown colouration. Along with the sesquioxides, lime and magnesia are also washed down to the second horizon. This brownish horizon, therefore, corresponds with the usual B-horizon of the international group of brown forest soil. The third horizon, however, shows

characteristic differences according to the topography of profile development. Along steep slopes this horizon is very light, loose, stony and structureless with a pre-eminently yellow colour, whereas at the flat end of hill-slopes this horizon consists of a brownish hard pan ; the latter is due presumably to hydrated ferric oxide, as on ignition the soil assumes a reddish brown colour. It is interesting to observe that plant-roots generally avoid the third horizon along steep slopes. Even grasses refuse to grow on this type of soil. This might be attributed either to the presence of some toxic ingredient in this horizon or absolute poverty in food material and moisture.

Chemical analysis does not, however, reveal any unusual deficiency in plant-nutrients and under field conditions sufficient moisture is found to be present. Thus it may be concluded that the aversion of the plant-roots to traverse this horizon is due to some toxic ingredient.

The formation of a brown hard pan in the third horizon under the topographical conditions stated above has sometimes been interpreted as characteristics of podsolic developments [Ramann, 1928]. Our studies, however, definitely show that brown forest soils as distinct from podsols can form hard pans under certain topographical conditions. Along steep slopes where brown soil formations take place, the subsoil drainage is roughly parallel to the surface and rock-bed. This is one of the reasons underlying the hydration of sesquioxides of the third horizon. The sesquioxide sol under such drainage conditions can move only along the B-horizon down the slopes ; but at places where this movement can take place vertically, as is the case at the flat end of the hills, the sol during dry period may be dehydrated and in course of time, as stated above, result in pan formation tending to the juxtaposition of the B and C-horizons.

The natural result of a hard pan in the sub-soil sooner or later affects the surface soil. With high rainfall and the blocking up of sub-soil drainage at the pan, sheet erosion might occur, with the result that a considerable quantity of organic matter is washed away from the surface soil. This appears to account for the poor organic status of the surface soil in most of the clay profiles.

Second in importance to the brown forest soils, podsolic formations are encountered under certain local conditions as has been stated already. The topographical position of these profiles is such that the soils experience alternate wetting and drying, a cool humid climate due to shady surroundings and above all sufficient organic matter accumulation due to annual leaf-fall in the spring. Under these conditions it is natural that podsols would develop. Most of the podsolic profiles studied by us are clayey to loamy, and two types of hard pans have been met with. The conditions favouring the formation of such pans have not been determined, excepting that humus pan has a lower *p*H than the iron pan. The study of these pans in the hills becomes more difficult when one finds these to be superimposed on the C-horizon with no well-defined line of separation.

Data have been presented about soils showing red loam and gleization tendencies. At any rate these are not typical formations of the station. The suggestion is clear, however, that if through human intervention or otherwise the specific conditions leading to their development be produced anywhere on the orchard, the soil in that locality would tend to assume the characteristics of red loam or Wiesenboden types.

It should, however, be clearly understood that most of the soils on this orchard are as yet somewhat immature as revealed by their stony nature. Although we have reported on four major types of the formation usually met with in this locality, the detailed survey has shown various intermediate developments which cannot be regarded as true pedogenic types. For instance, in some cases, it has been found that brownish grey organic surface soil is superimposed on a yellowish brown horizon which for true brown forest soils usually constitutes the C-horizon. But when this surface horizon is more closely examined a brownish layer of about one-tenth of an inch or so in thickness is usually found. This type of profile is very shallow and is found along slope of 60° or more.

The analytical data for the clay fraction of brown forest soils occurring on this orchard do not reveal any eluviation of the bases ; but in the case of podsols, on the other hand, considerable eluviation of Fe_2O_3 is observed to have taken place. The trend of the changes in the silica-sesquioxide ratios shows that physical weathering plays a more important part than chemical weathering in the formation of soils in these hills.

Summary

The pedogenic soil-forming processes under the climatic and topographical conditions of Chaubattia tend to produce four different soil types as given below :

Red loams

Soils corresponding to the temperate red-loams are found in dry places where the organic matter is rapidly mineralised owing to subsoil drainage conditions. Only a small number of profiles is found to possess these characteristics.

Brown forest soils

This formation is very general under the climatic conditions at Chaubattia and most of the soils of the locality belong to this type. The pre-eminent nature of the profiles of this type is brown colouration of the B-horizon and moderate organic status of the surface soil.

Podsols

The third formation which is met with under humid conditions shows podsolic tendencies although extreme cases of podsolization are not very evident.

Wiesenboden or meadow soils

The fourth type of development is analogous with the hydrogenic Wiesenboden formation and is usually found near *nullas* and in cool, shady and perpetually moist places.

REFERENCES

Aaltonen, V. T. (1938). *Trans. Second Comm. Int. Soc. Soil Sci.* **41**
Akimzev, V. V. (1930). *Proc. 2nd Int. Cong. Soil Sci.* **5** (1932), 195
Bal, D. V. (1925). *J. Agric. Sci.* **15,** 454
Baldwin (1928). *Proc. & Papers Int. Soc. Soil Sci.* **4,** 276
Basu, J. K. (1938). *Ind. J. Agric. Sci.* **8,** 637
Baver, L. D. (1933). *Agric. Eng. St. Joseph Mic.* **14,** 51
Bennett, H. H. (1926). *Soil Sci.* **21,** 349
Bouyoucos, G. J. (1935). *J. Amer. Soc. Agron.* **27,** 738
Dokuchaev, V. V. (1879). *Trans St. Perburg. Soc. Nat.* **10,** 64
Frosterus, B. (1914). *Inter. Mitt. Bodenkunde* **3,** 99
Gedroiz, K. K. (1929). '*On the absorbing properties of the soils*'. State Publishing House, Novaya Derevnya (Moscow, Leningrad)
Glinka, K. F. (1928). '*The great soil groups of the world and their development*'. (Translated by C. F. Marbut) : Edward Bros. Ann. Arbor. Mich., pp. 56, 64
Gorrie, R. M. (1937). *Herb. Rev.* **5,** 74
Harrasso Witz, H. (1930). *Gelberden Oder Gelblehme, Blank's Handbook der Bodenlehre* **3,** 182
Jenny, H. (1926). '*Die alpinen Boden*' *Denkshr. Schweiz Nalurforsch Gesell, Zurick*
———— (1930-31). *Hochgebingoboden, Blank's* '*Handbook der Bodenlehre*' **3,** 96
Joffe, J. S. (1936). '*Pedology*' : Rutgers University Press, N. J., p. 405
Kappen, (1927). *Trans. Comm. II Int. Soc. Soil Sci. (Groningen), B,* 179
Kellog, G. E. (1936). *U. S. D. A. Mis. Pub. No.* **229**
Lowdermilk, W. C. (1930). *J. Forestry* **28,** 474
Lutz, J. F. (1934). *Miss. Agric. Expt. Sta. Res. Bull.* **212,** 45
Mann, H. H. (1933). *J. Expt. Agric.* **1,** 245-52
Marbut, C. F. (1928). *Proc. & Papers Ist Int. Cong. Soil Sci.* **5,** 40
Mattson, S. (1933). *Soil Sci.* **36,** 149
Middleton, H. E. and Slater, C. S. (1932). *U. S. D. A. Tech. Bull.* **316**
Mil'er, M. F. (1931). *Science* **73,** 79
Mitchell, R. L. and Muir, A. (1935). *Trans. 3rd Int. Cong. Soil Sci.* **1,** 322
Morozov, S. S. (1938). *Pedology* **1,** 436
Neusyrauv, S. S. (1915). *Pochvovedemic* **17,** 62
Ramann, E. (1928). '*The evolution and classification of soils.*' (Translated by C. L. Whittle) : Heffer and Sons, Cambridge
Ramesov, N. P. (1937). *Pedology* **8,** 1139
Ramser, C. E. (1933). *Agric. Engin.* **14,** 103
Robinson, G. W. (1932). '*Soils, their origin, constitution and classification*' : Thomas Murby & Co., London, p. 278
Robinson, G. W. and Wasowicz, T. (1935). *Trans. 3rd Int. Cong. Soil Sci.* **1,** 310
Tamm, O. (1925). *Int. Rev. Sci. and Pruct. Agric.* **41,** 347
———— (1930). *Schwed. Forstvereins* **28,** 1
Throps, J. (1931). *Soil Sci.* **32,** 283
Tumin, G. M. (1911). *Zhur Oput. Agron.* **12,** 1-9
Vilenshi (1930). '*Guide book for the excursion of the 2nd Int. Soc. Soil Sci.*' Organising Com. Moscow II, 120
Walkley, A. and Black, I. (1934). *Soil Sci.* **37,** 29
Winter, E. (1938). *Soil Sci.* **46,** 33
Wright, C. H. (1934). '*Soil analysis, a handbook of physical and chemical methods,*' p. 169
Zokharov, S. A. (1927). '*Kurs Pochbevedeniya.*' Moscow, Leningrad

THE RELATION OF THE SIZE OF FRUIT TO THE LOSS IN WEIGHT IN STORAGE

BY

D. V. KARMARKAR, M.Sc., PH.D., A.I.I.Sc.

AND

B. M. JOSHI, M.Sc.

Cold Storage Research Scheme, Kirkee

(Received for publication on 9 February 1940)

THE processes of respiration and transpiration continuously go on in fruit during storage, with the result that the fruit gradually loses in weight. The rate of loss depends on the temperature and the relative humidity in the storage chambers and also on the nature of the fruit. Wardlaw [1933] in his experiments on the storage behaviour of limes observed that the loss in weight was largely a function of size and that such loss was directly related to the area of fruit exposed. Leonard [1936] found that, in the case of grape fruit, the percentage loss in weight was less in fruits of bigger size. Wardlaw and Leonard [1936] showed the importance of size involving surface-bulk relationship in considering the rate of loss in weight during storage. Cheema and others [1939] found that, in the case of mangoes, the percentage loss in weight of small fruit was higher than that of big fruit at 68°F., but there was no difference at 48°F. Cheema and Karmarkar [1939] observed that in Malta oranges the size of fruit was very important. Fruit of big size remained firm, while fruit of small size shrivelled. During the course of the experiments conducted in this cold storage plant it has been found that the size of fruit influenced the rate of loss in weight in storage. The data obtained with different fruits are given in this paper.

EXPERIMENTAL PROCEDURE

Big and small size fruit of an apparently equal stage of maturity was selected for the experiments. The selection of the two sizes was made according to the weight of fruit as the specific gravity did not vary appreciably with the size. Ten fruits of each size (weighing within a selected range) were used. The fruits were individually weighed and kept in partitioned trays. One fruit was kept in each division and the partitions were given serial numbers so that in case a fruit rotted, it could be removed without disturbing the experiment. The fruits were kept in chambers maintained at different temperatures with the relative humidity between 80 and 90 per cent. The fruits were weighed at regular intervals and the rate of loss in weight was determined. The percentage loss in weight was calculated on fresh-weight basis. The ratio of percentage loss in weight of small fruit to the percentage loss in weight of big fruit was also obtained. Further, the thickness of skin, the percentage of pulp and the rate of respiration of fruits of the two sizes were determined. The data are given in Tables I-XI. The number within brackets just below the range of weights indicates the average weight of a fruit in grammes. For brevity the ratio of the percentages is shown as small/big or as big/small.

Discussion

The loss in weight in storage of fruits is due to the transpiration of water from the tissues and the decrease in solids during respiratory processes. A little loss may also be due to the evaporation of other volatile substances given off by the fruits. Wardlaw [1933], Leonard [1936] and Wardlaw and Leonard [1936] have noticed that the rate of percentage loss in weight in storage of fruits is related to the size of fruit and is greater in fruits of smaller size. The greater loss in weight of small fruit may be due to the larger surface exposed per unit volume resulting in a higher rate of transpiration. The data obtained in these experiments (Tables I—VIII) showed that the percentage loss in weight of small fruit was always greater than that of big fruit, except in the case of grape fruit at 68°F. The ratio of the percentage loss in weight of small fruit to the percentage loss in weight of big fruit remained practically constant during the storage period. The value of the ratio, however, was found to vary with the temperature of storage. In limes (Table V) the small/big ratio at 45°F. agreed well with the ratio for surface (big and small fruits) which was 1·24 when calculated by assuming limes to be of a perfect spherical shape. Resorting to the above method of calculating the surface ratio, the small/big ratio approximated the surface ratio which was 1·14 in the case of Mosambi and Malta oranges at the different temperatures. The calculated surface ratio in the case of the Nagpur orange was 1·15 and was equal to the small/big ratio at 52°F. only (Table VIII).

The high values of small/big ratio obtained in the case of chikoos (Table II), bananas (Table III) and limes (Table V) at 68°F. and the Nagpur orange (Table VIII) at 40° and 45°F. could not be accounted for by the surface-bulk relationship alone. The difference in the small/big ratios obtained for the same type of fruit at different temperatures of storage suggested that there were other factors which influenced the ratio.

Table I

Apples (variety, Hawthorn Greening)

Number of days of storage	Percentage loss in weight at 68°F.		
	Big 130-140 gm. (134)	Small 90-96 gm. (92)	Small/Big
8 . . .	1·51	1·67	1·11
16 . . .	2·67	2·85	1·07
24 . . .	3·80	4·08	1·07
32 . . .	4·85	5·24	1·08

TABLE II

Chikoo (Achras sapota, *globular type*)

Number of days of storage	Percentage loss in weight					
	52°F.			68°F.		
	Big 90-105 gm. (98)	Small 65-70 gm. (67)	Small / Big	Big 90-100 gm. (94)	Small 60-70 gm. (64)	Small / Big
3 . . .	..	..	..	3·13	4·30	1·37
5 . . .	3·22	3·92	1·22	..	..	..
6 . . .	..	..	..	5·98	8·14	1·37
9 . . .	..	..	..	9·06	11·45 (turned soft)	1·26
10 . . .	6·17	7·41	1·20	..	..	..
15 . . .	9·44	11·30	1·20	..	..	..
20 . . .	11·48	13·67	1·19	..	..	..

TABLE III

Banana (*variety, Walha*)

Number of days of storage	Percentage loss in weight					
	52°F.			68°F.		
	Big 105-120 gm. (113)	Small 65-80 gm. (69)	Small / Big	Big 105-120 gm. (112)	Small 60-75 gm. (67)	Small / Big
4 . . .	3·04	3·32	1·09	3·15	4·74	1·51
9 . . .	5·95	7·19	1·21	6·27	9·77	1·56
13 . . .	8·04	9·81	1·22	9·15	13·95	1·52
17 . . .	9·97	12·25	1·23	11·63	19·34	1·66
21 . . .	11·88	14·59	1·23	..	..	..

TABLE IV

Grape fruit (*variety, Marsh's Seedless*)

Number of days of storage	Percentage loss in weight					
	45°F.			68°F.		
	Big 510-530 gm. (518)	Small 300-330 gm. (314)	Small / Big	Big 540-560 gm. (548)	Small 300-330 gm. (315)	Small / Big
8 . . .	1·37	2·03	1·48	3·10	2·89	0·93
16 . . .	2·94	3·46	1·18	5·63	5·43	0·96
24 . . .	4·58	4·82	1·05	7·57	7·15	0·94
32 . . .	6·29	6·53	1·04	8·73	8·22	0·94
40 . . .	..	..	..	10·01	9·48	0·94

TABLE V

Limes (Citrus aurantifolia ; *variety, Kagadi*)

Number of days of storage	Percentage loss in weight					
	45°F.			68°F.		
	Big 50-60 gm. (53)	Small 20-25 gm. (23)	Small / Big	Big 50-60 gm. (54)	Small 20-25 gm. (24)	Small / Big
4 . . .	5·94	8·01	1·35	2·96	4·16	1·40
8 . . .	10·33	13·24	1·28	5·18	7·25	1·40
12 . . .	13·00	16·37	1·26	6·52	8·86	1·36
16 . . .	16·77	20·94	1·25	8·63	11·49	1·33
20 . . .	19·36	24·07	1·24	10·36	13·78	1·33

TABLE VI

Mosambi (Orange Mozambique)

Number of days of storage	Percentage loss in weight					
	45°F.			68°F.		
	Big	Small	Small / Big	Big	Small	Small / Big
	280-300 gm. (288)	190-210 gm. (202)		260-270 gm. (265)	170-190 gm. (180)	
9 . . .	1·61	1·79	1·11	1·96	2·32	1·18
17 . . .	2·88	3·27	1·13	3·32	3·92	1·18
25 . . .	4·08	4·66	1·14	3·95	4·70	1·19
33 . . .	5·28	5·99	1·13	4·54	5·44	1·20

TABLE VII

Malta orange (variety, Blood Red)

Number of days of storage	Percentage loss in weight								
	35°F.			40°F.			45°F.		
	Big	Small	Small / Big	Big	Small	Small / Big	Big	Small	Small / Big
	260-280 gm. (270)	140-180 gm. (166)		255-295 gm. (271)	130-170 gm. (152)		260-300 gm. (280)	140-180 gm. (163)	
16 . .	4·91	6·24	1·27	7·20	7·44	1·03	7·28	8·44	1·16
34 . .	10·02	12·09	1·21	13·68	15·77	1·15	14·20	16·60	1·17
50 . .	14·37	16·89	1·18	19·67	23·19	1·18	20·13	23·44	1·17
68 . .	19·23	21·73	1·13	26·07	30·55	1·17	27·06	29·90	1·11
85 . .	23·42	25·61	1·09	31·51	36·35	1·15	32·74	35·63	1·09

TABLE VIII

Nagpur orange

Number of days of storage	Percentage loss in weight															
	35°F.			40°F.				45°F			52°F.			68°F.		
	Big	Small	Small / Big	Big	Small	Small / Big	Tight-skinned	Big	Small	Small / B	Big	Small	Small / Big	Big	Small	Small / Big
	200-230 gm. (218)	130-160 gm. (143)		220-270 gm. (234)	130-160 gm. (148)		130-160 gm. (147)	190-230 gm. (208)	140-180 gm. (159)		195-225 gm. (207)	130-170 gm. (149)		210-230 gm. (221)	130-160 gm. (146)	
9 . . .	1·45	1·56	1·08	1·51	2·17	1·44	1·73	1·53	1·91	1·25	2·40	2·72	1·13	4·03	4·27	1·06
17 . . .	2·44	3·03	1·24	2·73	3·91	1·43	3·17	2·70	3·65	1·35	3·95	4·52	1·14	6·14	6·46	1·05
26 . . .	3·59	4·53	1·26	4·17	6·00	1·44	4·88	3·97	5·56	1·40	3·59	6·38	1·14	8·24	8·97	1·09
34 . . .	4·63	5·77	1·24	5·46	7·88	1·44	6·44	5·19	7·25	1·40	7·10	8·17	1·15	...	...	...
42 . . .	5·68	7·12	1·25	6·77	9·73	1·44	8·00	6·43	8·92	1·39	8·59	9·92	1·15	...	...	...
51 . . .	7·10	9·35	1·31	8·32	11·88	1·43	9·73	7·87	10·84	1·38	10·34	12·01	1·16	...	...	...
59 . . .	8·11	10·14	1·25	9·57	13·61	1·42	11·23	9·09	12·50	1·38	11·90	13·62	1·15	...	...	...
67 . . .	9·35	11·49	1·23	10·40	15·35	1·48	12·74	10·30	14·12	1·37	13·53	15·04	1·11	...	...	...
77 . . .	10·81	13·13	1·21	12·40	17·48	1·41	14·47	11·78	16·07	1·36	15·57	17·06	1·10	...	...	...

TABLE IX

Thickness of the skin of big and small fruits

Name of fruit	Thickness in cm.		
	Big	Small	Big / Small
Banana . .	0·31	0·22	1·41
Grape fruit .	0·43	0·35	1·23
Limes . .	0·12	0·09	1·42
Mosambi . .	0·38	0·28	1·36
Nagpur orange .	0·29	0·23	1·26

TABLE X

Percentage of pulp in big and small fruits

Name of fruit	Percentage of pulp		
	Big	Small	Small / Big
Banana . .	58·4	62·5	1·07
Grape fruit .	77·0	76·6	..
Limes . .	81·4	83·7	1·03
Mosambi . .	74·8	74·2	..
Nagpur orange .	74·0	77·6	1·05

TABLE XI

Rate of respiration of big and small fruits at 68°F.

Name of fruit	Parts of CO_2 per 100 gm. of fruit per 24 hours		
	Big	Small	Small / Big
mes .	32·1	38·1	1·19
osambi . .	14·5	18·0	1·24
agpur orange .	22·2	24·8	1·12

The skin of fruit plays an important part in regulating the gaseous exchange between the tissues and the atmosphere around the fruit. The absorption of oxygen and the excretion of carbon dioxide and water vapour take place through the skin by diffusion. The rate of diffusion of the gases depends on the permeability of the skin. It has been found that the thickness of the skin of small fruit was less than that of big fruit (Table IX). The rate of gaseous diffusion may, therefore, be more rapid in small fruit and consequently lead to a greater evaporation of water from the pulp tissues resulting in a greater loss in weight.

It is also possible that the greater loss in weight of small fruit may be the result of a higher rate of respiration. The small fruit may respire more than the big fruit on account of a relatively larger surface per unit volume or more rapid diffusion of gases through the thinner skin. The higher rate of respiration may be partly due to a larger proportion of pulp in small fruit. It has been found that in the case of bananas, limes and Nagpur oranges, the percentage of pulp in small fruit was higher than that in big fruit (Table X). The percentages of pulp in Mosambi and grape fruit of the two sizes were practically equal.

Gustafson [1929] conducted some experiments with tomatoes to determine whether the size of the fruit exerted any influence on the rate of respiration, but nothing definitely was ascertained though, in some cases, it seemed that larger fruits respired less per gram of material than smaller fruits of the same age. In these experiments the determination of the rate of respiration at 68°F. of fruits of the two sizes showed that the rate of respiration was higher in the case of small fruit (Table XI). It is necessary, however, to consider these values with some reservation as it is very difficult to get fruit of two sizes at the same stage of physiological development for proper comparison and considerable variation often exists among individual fruits.

The values obtained for the small/big ratio in the case of Nagpur oranges (Table VIII) stored at different temperatures were interesting. The values at 40° and 45°F. were high and approximately equal. The rates of loss in weight at these two temperatures were also nearly equal. The value of the ratio was lower at 35°F. and equalled the ratio of the skin thicknesses. The value at 52°F., as previously mentioned, was equal to the surface ratio, while the value at 68°F. approximated the pulp ratio. Loftfield [1921] has shown that the temperature influences the stomatal movement, the rate of movement increasing with temperature. If it could be assumed that the stomata were wide open at 68°F. and a free exchange of gases took place the quantity of the pulp would determine the rate of loss in weight. At 52°F. the stomata might be open in the normal way and an easy diffusion of gases would take place, the rate of loss in weight depending on the area of the surface exposed. At 40° and 45°F. the stomata might be just open so that the thickness of the skin determined the rate of exchange of gases and the value of the ratio small/big represented the combined effect of the surface, pulp and thickness of the skin ratios. In Nagpur oranges, which are ordinarily puffy and loose-skinned, there are some fruits which are tight-skinned and more compact. The rate of diffusion of gases in such oranges is expected to be slower than that in puffy fruits. The rate of loss in weight of tight-skinned oranges was found to be less than that of puffy fruit of approximately equal volume.

In the case of the Malta orange, big fruit kept in storage a much fresher appearance than small fruit which appeared shrivelled. The skin dried up and assumed a dull colour. It is possible that the aperture of stomatal pores in the skin of small fruit may be smaller than that in the case of big fruit. The higher rate of transpiration leads to loss of turgidity of the cells which may effect a partial closure of stomata so that a major portion of the loss in weight takes place from the skin which, in the course of time, shows shrivelling.

Summary

1. The percentage loss in weight in storage at different temperatures of fruits of two sizes, big and small, has been determined. The fruits used were apples, chikoos, bananas, grape fruits, limes, Mosambi, Malta oranges and Nagpur oranges. The data showed that the loss in weight of small fruit was always greater than that of big fruit, except in the case of grape fruit at 68°F.

2. The thickness of the skin, the percentage of pulp and the rate of respiration of fruits of the two sizes have been determined. The skin of small fruit was found to be thinner than that of big fruit. In bananas, limes and Nagpur oranges the percentage of pulp in small fruit was a little higher than that in big fruit. The rate of respiration of small fruit was also greater than that of big fruit.

3. The ratio of the percentage loss in weight of small fruit to the percentage loss in weight of big fruit remained practically constant during the storage period. The value of the ratio, however, varied with the temperature of storage.

4. The higher percentage loss in weight of small fruit could be correlated in some cases to the relatively greater surface per unit volume of fruit exposed. The ratio small/big was found to be approximately equal to the surface ratio in the case of limes (stored at 45°F.), Mosambi, Malta oranges and Nagpur oranges (stored at 52°F.).

5. It has been suggested that the comparatively thinner skin of small fruit facilitated a more rapid diffusion of gases which resulted in a higher rate of evaporation of water from the pulp and possibly in a higher rate of respiration as well.

6. The difference in the values of small/big ratio obtained at different temperatures in the case of Nagpur oranges has been discussed.

The authors wish to acknowledge the assistance of Messrs R. K. Lavlekar and S. W. Rane in this work.

REFERENCES

Cheema, G. S. and Karmarkar, D. V. (1939). *Imp. Counc. Agric. Res. (India) Misc. Bull.* **23**

Cheema, G. S., Karmarkar, D. V. and Joshi, B. M. (1939). *Imp. Counc. Agric. Res. (India) Misc. Bull.* **21**

Gustafson, F. G. (1929). *Plant Physiol.* **4**, 348

Leonard, E. R. (1936). *Low Temp. Res. Sta. (Trinidad) Mem.* **2**

Loftfield, (1921). *Carnegie Inst. Wash. Pub.* **314**

Wardlaw, C. W. (1933). *Trop. Agric.* **10**, 246

Wardlaw, C. W. and Leonard, E. R. (1936). *Low Temp. Res. Sta. (Trinidad) Mem.* **3**

VARIETIES OF CARDAMOM IN CULTIVATION IN MYSORE

BY

R. L. NARASIMHA SWAMY, M.Sc.

Geneticist, Coffee Experiment Station, Balehonnur

(Received for publication on 9 January 1940)

(With Plate XLVI)

Introduction

BAKER [in Hooker, 1894] and Fischer [1928] have mentioned *Elettaria cardamomum* Maton. growing in South India. They have further made mention of a single variety *E. cardamomum* Maton. var. *major* Thw. This variety has been stated to be a robust plant with leaves broader than the type and having oblong-fusiform fruits 1 in. or more long and indigenous in Ceylon [Hooker, 1892]. Thwaites gives the habitat of the variety as ' forests in the central and southern provinces, up to an elevation of 3,000 ft.'

Ridley [1912] mentions that ' there are two distinct forms or varieties of the plant, viz. var. *minus*, the Malabar cardamom, a taller plant with narrower and less firm leaves and globose fruits from 1/5 to 9/10 in. long, greyish yellow or buff in colour. This is confined to southern India. Var. *majus* with shorter stems, broader leaves and oblong fruit, from 1 to 2 in. long, and rather narrower than the Malabar fruit, distinctly three-sided, often arched and dark-greyish brown when dry, the seeds larger and more numerous, and less aromatic. This is the Ceylon cardamom and peculiar to that country.' Molegode [1938] reports that three varieties of *Elettaria cardamomum* Maton. are found in Ceylon. One of these is indigenous to Ceylon. The cultivated varieties, Malabar and Mysore, appear to have been introduced from India. The Malabar variety is described : ' Leaves silky on the under-surface ; recemes arise from the base of the stem and creep on the surfae of ground around the clumps ; fruits or capsules angled, shorter and more globular than the Mysore type.' The Mysore variety is described : ' Leaves larger with a coarser under-surface, not silky but hard and smooth ; racemes rise erect ; fruits oblong and larger than those of the Malabar type.'

Material and methods

A number of collections of cardamoms from several localities in South India are growing on the Government Coffee Experiment Station, Balehonnur. The collections were made by Mr K. H. Srinivasan, M.A., B.Sc. (Edin.). I began studying these with a view to classifying them. During the course of study the principal cardamom-growing areas in Mysore that are round about Manjarabad were visited and the cardamoms growing there were studied. As a result it was observed that though cardamoms growing in Mysore belong to the species *Elettaria cardamomum* Maton. there are well-marked differences suggesting the existence of distinct varieties. These could not be classified according to the described varieties. Further, it was observed that the description of the species also required certain changes. In the present paper

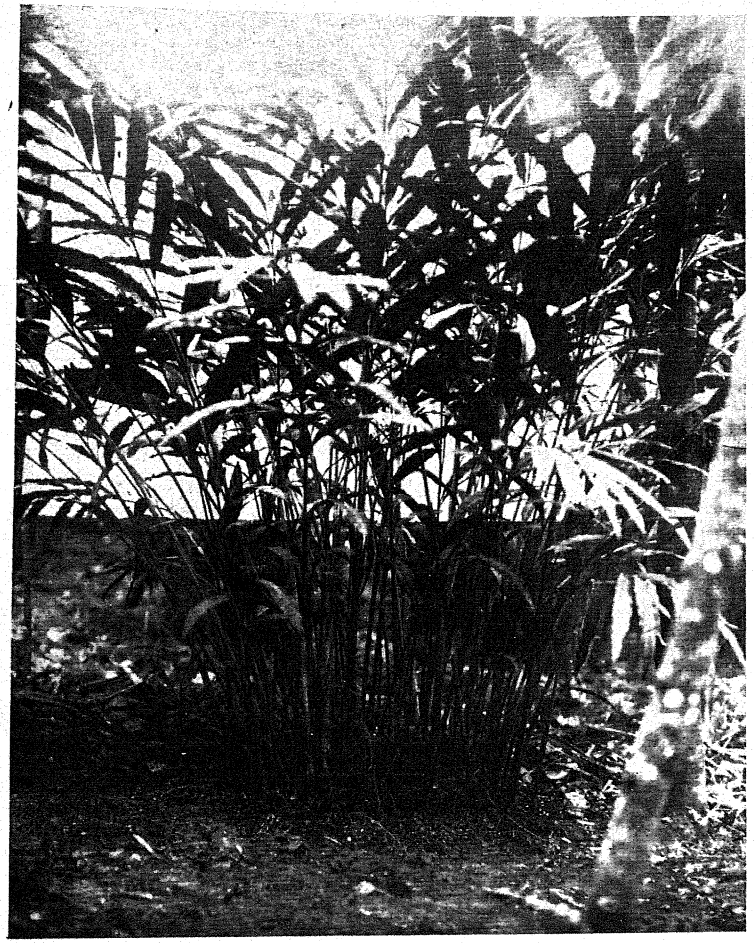


FIG. 1. *Elettaria cardamomum* Maton.—general habit

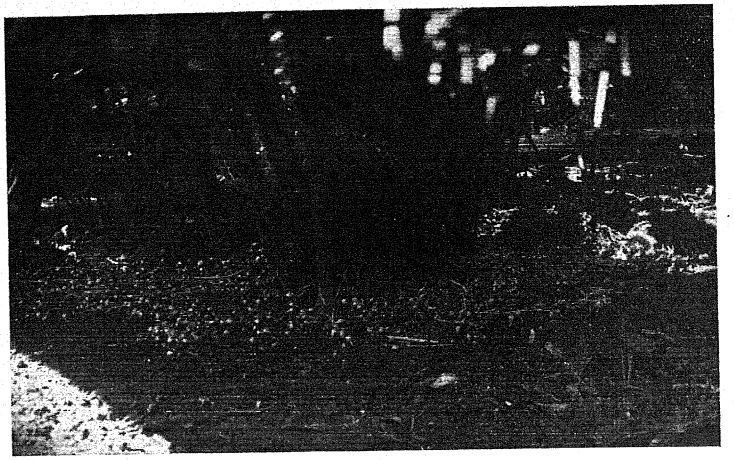


FIG. 2. *Elettaria cardamomum* Maton.—fruiting habit

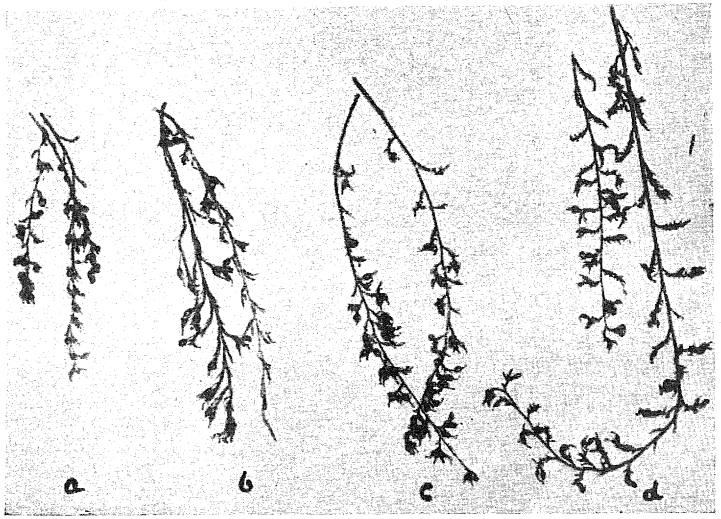


FIG. 3. Panicles of (*a*) *Elettaria cardamomum* Maton; (*b*) var. *laxiflora;* (*c*) var. *mysorensis;* (*d*) var. *major*

three varieties have been described and some changes in the description of *Elettaria cardamomum* Maton. given in Hooker [1894] and Fischer [1928] are introduced.

All the detailed observations were done on plants growing on the Station side by side under identical climatic conditions and these were supplemented by general observations on plants in the cardamom estates round about Manjarabad.

Description

Elettaria cardamomum Maton. (Plate XLVI, figs. 1, 2, 3*a*).—Perennial herb; rootstock horizontal ; leafy stem tall, 5 ft.-11 ft. high ; leaves distichous, linear lanceolate, acuminate, sessile or shortly petioled up to 0·75 in. ; glabrous above, glabrous or softly pubescent beneath, 1 ft.-2·5 ft. long, 1·75 in-4·75 in. broad ; margin wavy. Panicles produced direct from the rootstock, flexuous, decumbent, several to one leafy stem, up to about 2 ft. long ; bracts linear-oblong, obtuse, about 1·5 in. long ; flowers produced in 2 to 12 flowered short racemes 0·5 in.-3·5 in. long ; bracteolate, shortly pedicelled. Calyx membranous tubular, shortly three lobed, 0·5 in.-0·7 in. long, persistent. Corolla tube cylindric, white, shortly exserted, 0·75 in. long ; lobes spreading, mid-lobe oblong, convex ; lateral narrower ; lobes 0·5 in. long. Lip oblong-obovate, longer than the corolla lobes, 1 in. × 0·72 in., base cuneate, margin wavy ; white striped with violet ; lateral staminodes minute teeth ; two staminodes at the base of the corolla tube ; stamen with a short filament ; anther not crested, its cells contiguous ; longitudinally dehiscing. Ovary three celled ; ovules many 2-seriate in each cell, axile ; style filiform, 1·2 in. long ; stigma small, funnel shaped, ciliate. Fruit a sub-globose, sub-trigonous, coriaceous, indehiscent capsule, 0·4 in.-0·7 in. × 0·3 in.-0·5 in., striate, pale yellow when ripe ; each cell contains three to eight seeds. Seeds obovoid, angular by compression, transversely wrinkled, aromatic, arillate.

Var. *laxiflora* (Plate XLVI, fig. 3*b*).—Leafy stemup to 14 ft. Leaves 11in.-2·75 ft. × 1·5 in.-5·5 in., shortly petioled or not, glabrous on both sides Panicles flexuous, up to 4·25 ft. long, lax, decumbent. Flowers produced in 4 to 40 flowered short lax racemes, 0·5 in.-5 in. long. Pedicel up to 1 in. long. Capsules very variable, oblong to oblong-fusiform, 0·5 in.-1 in. × 0·3 in.-0·5 in. ; each cell contains two to nine seeds.

Var. *Mysorensis* (Plate XLVI, fig. 3*c*).—More robust. Leafy stem up to 17 ft. high. Leaves 1·2 ft.-2·6-ft. × 2 in.-6·25 in., glabrous on both sides, or glabrous above and pubescent beneath, petiole up to 1·5 in. long. Panicles flexuous or not up to 4·75 ft. long, erect or decumbent. Flowers produced in 4 to 35 flowered short racemes, 0·5 in.-6·5 in. long. Lip broader 1·2 in. × 1 in. Capsule bigger 0·5 in.-0·8 in. × 0·35 in.-0·6 in., distinctly three-angled ; each cell contains three to nine seeds.

Var. *major* Thw. (Plate XLVI, fig. 3*d*).—More robust. Leafy stem up to 18 ft. high. Leaves 1 ft.-2·75 ft. × 2 in.-6·5 in., pronouncedly petioled, petiole up to 2 in. long, glabrous on both sides. Panicles not flexuous, up to 4·5 ft. long, erect. Flowers produced in 6 to 40 flowered short racemes 0·5 in-4·5 in. long. Lip broader 1·2 in. × 1 in. Capsule oblong-fusiform, 0·5 in.-0·8 in. × 0·3 in.-0·45 in. ; each cell contains three to six seeds. Seeds are arger and slightly flatter.

Habitat description

The varieties are cultivated to a greater or lesser extent in almost all the estates in Mysore. Var. *laxiflora* has not been obtained from outside Mysore. It has been observed growing in the cardamom estates round about Manjarabad. Var. *major* Thw. is stated by planters as obtained either from Ceylon or from Annamalais. At the Station, plants have been raised from seeds obtained from Annamalais, Travancore and estates in Mysore. All these are similar and belong to the variety *major* Thw. Plants of var. *Mysorensis* have also been raised from seeds obtained from several estates in South India, so that the habitat of the variety may be said as South India and under cultivation.

Discussion and conclusions

There are differences between the description of *Elettaria cardamomum* Maton. by Baker [in. Hooker, 1894] and Fischer [1928], and the description in the present paper. They mention that the species has leaves that are pubescent beneath ; bracts two to seven flowered ; seeds not arillate. I have found that the leaves are either glabrous or pubescent beneath ; flowers are produced in 2 to 12 flowered short racemes in the panicles ; seeds are arillate. Further, the presence of two staminodes at the base of the corolla tube has been reported by the author [Narasimha Swamy, 1937]. It is observed that Malabar cardamom of Molegode [1938] corresponds to the type described.

Var. *major* Th. has been mentioned by Baker [in Hooker, 1894] and Fischer [1928]. The present description of the variety differs in having 6 to 40 flowered short racemes in the panicle and fruits that are 0·5 in.-0·8 in. long.

Var. *Mysorensis* appears to correspond with the Mysore cardamoms of Molegode [1938] though the former differs in having leaves that are glabrous or pubescent beneath and panicles that are erect or decumbent.

Var. *laxiflora* appears to have not been described so far. Glabrous leaves, lax decumbent panicles having 4 to 40 flowered short lax racemes that have flowers with long pedicels, and fruits which are often elongated clearly distinguishes this variety.

Summary

Elettaria cardamomum Maton. var. *laxiflora*, var. *Mysorensis*, var. *major* Thw. have been described.

Acknowledgements

I am deeply indebted to Mr K. H. Srinivasan, M.A., B.Sc. (Edin.), for kindly allowing me to make use of the material collected by him, and for the encouragement given by him and Mr W. W. Mayne, B.Sc., during the course of the study.

References

Fischer, C. E. C. (1928). *Flora of the Presidency of Madras*, Part VIII, p. 1491
Hooker, J. D. (1894). *Flora of British India* **6**, 251
Molegode, W. (1938). *Trop. Agric.* **7**, 325
Narasimha Swamy, R. L. (1937). *Current Sci.* **5**, 427
Ridley, Henry N. (1912). *'Spices'* pp. 325, 7
Thwaites, G. H. K. *'Enumeratio Plantarum Zeylanicae,'* p. 318

RESEARCH NOTE

CHROMOSOME NUMBER IN BAMBOO (*DENDROCALAMUS STRICTUS*)

BY

R. H. RICHHARIA

AND

J. P. KOTWAL

Agricultural Research Institute, Nagpur, C. P.

(Received for publication on 14 August 1939)

(With one text-figure)

DURING 1938-39, a few plants of *Dendrocalamus strictus* along the road-sides of the Maharaj Bagh Gardens, Nagpur, exhibited flowering. Seeds were collected from these plants in the beginning of February 1939 for chromosome studies. There is no record of such observations in this species in any Indian publication.

The seeds were kept for germination in two lots, i.e. on 2nd and 4th of March respectively, on moist filter papers in Petri dishes. The first lot showed cent per cent germination, while the second lot only 67 per cent. In three days the root tips were ready for fixation. The following Navashin's solution, modified in our laboratory, was used with satisfactory results, followed by the iodine-gentian violet staining. Paraffin sections were cut at 15 μ.

Chromic acid 1 per cent . . .	5 c. c.
Formalin 20 per cent	3 c. c.
Glacial acetic acid	1 c. c.

Seventy-two chromosomes were distinctly observed on the metaphase plates of the root-tip cells (Fig. 1). The number was confirmed from several plates.

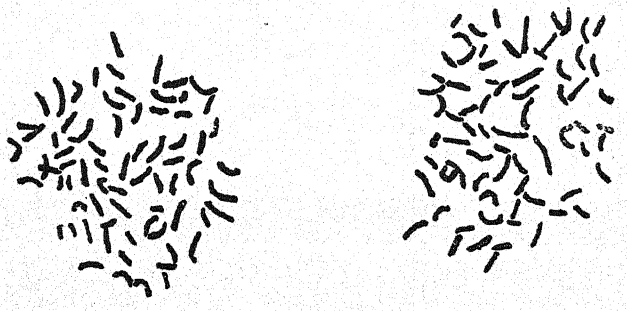


Fig. 1. Somatic chromosomes from *Dendrocalamus strictus* ($2n=72$) ($\times$ 3,200)

REVIEWS

FORESTRY ABSTRACTS

THE Imperial Forestry Bureau is publishing a quarterly journal entitled *Forestry Abstracts*. This provides a survey in English of the current literature of forestry from all parts of the world. Each issue normally includes special reviews of the literature of particular subjects, notes on annual reports, and abstracts classified by subject. In the abstracts the aim is to epitomize the contents of each paper so as to enable the reader to judge of its value as a contribution to knowledge. In addition to papers in English, French and German, attention is also directed to those published in the less familiar languages.

The first number appeared in June 1939 and deals mainly with the literature of 1938. Thereafter *Forestry Abstracts* is appearing quarterly in September, December, March and June, four numbers constituting a volume. Indexes will be provided annually.

The annual subscription is:—

For residents of the countries of the British Commonwealth and the Anglo-Egyptian Sudan who send their subscriptions direct to the Bureau	20*s.*
For all other subscribers	25*s.*
Single parts each	7*s.* 6*d.*

All these prices include postage. Particulars of trade terms will be supplied on request by the Secretary, Imperial Agricultural Bureaux, 2, Queen Anne's Gate Building, London.

TABLE OF CONTENTS

GENERAL FORESTRY

Theories. Terminology. Methods. Education. Research. Travel and study. Forest History and Geography.

FUNDAMENTAL NATURAL LAWS OF THE FOREST

Locality. Study of locality. Maintenance of locality factors. Soil. Hydrographical conditions. Forest and Water. Forest and Climate. Erosion.

TREE SPECIES. FOREST BOTANY

Physiology. Biology. Pathology. Morphology. Anatomy. Mode of life. Adaptability. Geographical distribution. Plant Geography and sociology. Regional floras. Special (Systematic) Botany.

FOREST ZOOLOGY

SILVICULTURE

Silvicultural characters. Systems of management. Forms of stand. Formation of stands, natural and artificial. Afforestation. Education of stands. Tending. Thinning.

UTILIZATION. TECHNOLOGY

Properties of wood. Harvesting of wood. Logging. Conversion. Preservation. Minor Forest Products. Sale and Disposal. Timber Trade. Transport. Constructional works.

PROTECTION

Forest fires. Protection against damage by harmful plants. Protection against damage by animals.

INCREMENT. YIELD

MANAGEMENT. WORKING PLANS. SURVEYS

ECONOMICS. VALUATION. FINANCE. PROFIT AND LOSS

ADMINISTRATION

POLICY

SUPPLEMENT TO THE REVIEW OF APPLIED MYCOLOGY

A SUPPLEMENT to the *Review of Applied Mycology* is now available giving a list of all new species and varieties of fungi, new combinations, and new names published since the beginning of 1940 in journals accessible to the Institute up to the end of June. It is hoped it may be possible to issue a further supplement early in 1941. The list is arranged alphabetically under the genera, and a host index is supplied. The Director will be grateful for the notification of omissions for inclusion in any subsequent issue.

The price of supplement 1 is 2*s*. 6*d*. post free (2*s*. post free to direct subscribers in the British Commonwealth) payable in advance. Orders and correspondence respecting the Supplement should be sent to the Director, Imperial Mycological Institute, Kew, Surrey.

GIPD—S3—310 IC of AR—14-12-40—750.